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PERIODICAL EVENTS AND NATURAL LAW AS GUIDES TO AGRICULTURAL RESEARCH AND PRACTICE.

BY

ANDREW DELMAR HOPKINS, Forest Entomologist.

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During the summer of 1913 the system of issuing publications of the Department of Agriculture was changed and simplified so as to eliminate numerous independent series of Bureau bulletins. In accordance with this plan, among other changes, the series of quarto bulletins—lettered from A to Z—and the octavo bulletins—numbered from 1 to 44—formerly issued by the U. S. Weather Bureau have come to their close.

Contributions to meteorology such as would have formed bulletins are authorized to appear hereafter as Supplements of the MONTHLY WEATHER REVIEW. (Memorandum from the Office of the Assistant Secretary, May 18, 1914.)

These supplements comprise those more voluminous studies which appear to form permanent contributions to the science of meteorology and of weather forecasting, as well as important communications relating to the other activities of the U. S. Weather Bureau. They appear at irregular intervals as occasion may demand, and contain approximately 100 pages of text, charts, and other illustrations. Subscribers to the MONTHLY WEATHER REVIEW receive the SUPPLEMENTS without extra charge. Copies may be procured at the prices indicated below by addressing the Superintendent of Documents, Government Printing Office, Washington, D. C.

SUPPLEMENTS PUBLISHED.

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No. 2. I. Calendar of the leafing, etc., of the common trees of the eastern United States. By G. N. Lamb. 19 p. 4 figs. II. Phenological dates, etc., recorded by T. Mikesell at Wauseon, Ohio. By J. Warren Smith. 73 p. 2 figs. Washington, 1915. 4°. Price 25 cents. (W. B. No. 558.)

No. 3. (*Aerology No. 1.*) Sounding balloon ascensions at Fort Omaha, Nebr., May 8, 1915, etc. By W. R. Blair and others. 67 p. 23 figs. Washington, 1916. 4°. Price 25 cents. (W. B. No. 592.)

No. 4. Types of anticyclones of the United States and their average movements. By E. H. Bowie and R. H. Weightman. Washington, 1917. 25 p. 7 figs. 73 ch. 4°. Price 25 cents. (W. B. No. 600.)

No. 5. (*Aerology No. 2.*) Free-air data at Drexel Aerological Station: January, February, and March, 1916. By W. R. Blair and others. Washington, 1917. 59 p. 6 figs. 4°. Price 25 cents. (W. B. No. 603.)

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No. 8. (*Aerology No. 4.*) Free-air data at Drexel Aerological Station: July, August, September, October, November, and December, 1916. By W. R. Gregg and others. Washington, 1918. 111 p. 12 figs. 4°. Price 25 cents. (W. B. No. 642.)

No. 9. Periodical events and Natural Law as guides to agricultural research and practice. By A. D. Hopkins. Washington, 1918. 42 p. 22 figs. 4°. Price 25 cents. (W. B. No. 643.)

PERIODICAL EVENTS AND NATURAL LAW AS GUIDES TO AGRICULTURAL RESEARCH AND PRACTICE.

By Andrew Delmar Hopkins, Forest Entomologist.

[U. S. Bureau of Entomology, Washington, D. C., Jan. 16, 1918.]

CONTENTS.

INTRODUCTORY.

The object of this paper is to make available for agricultural research and practice certain information which has been gained from an extended investigation of the principles and laws which govern periodical events in the seasonal history of forest insects and the time for the most effective treatment to control or prevent their depredations. It is intended to show that there is in general a safest and best time for periodical farm and garden practice to guard against or control insect and other enemies and to secure the best returns from the expenditure of money and labor and, by means of maps and calendars and tables of periodical events in the seasonal activities of common plants, to show how the safest and best time for certain kinds of periodical practice can be approximately determined for any place in the country. A further object is to give examples of the application of our present knowledge of a bioclimatic law to research and practice with the hope that these examples, empirical as some of them are, will serve as guides to the further investigations which are required, in various branches of science for all sections of the country, to furnish more exact information for immediate application in practice.[1]

Needs of Natural Guides as Recognized in Early Practice.

The need of natural guides to the best time, during the progress of the seasons, to do certain periodical farm and garden work, such as seed time and harvest, has doubtless been recognized since the dawn of primitive agriculture. The beginning of growth, the flowering of plants, and the appearance of certain kinds of birds and insects, which mark the advent of spring, have evidently been recognized by primitive man in all countries as guides to his hunting, fishing, and other periodical pursuits. The pioneer emigrants to this country evidently utilized the knowledge of such guides as applied to the plants they brought with them and gained additional information from the native Indians as to the value of periodical events in native plants as guides to the adaptation of their agricultural practice to their new environments. For example the shadbush was so-called because it was recognized by fishermen that when it was in bloom along the tidewater region of the Atlantic coast it was time to fish for shad. It was early recognized by the white settlers in the East, or probably the information was supplied by the Indians, that it was time to plant corn when the white oak or maple leaves were the size of squirrel feet, squirrel ears, or "mouse ears," according to various interpretations, or when the dogwood began to show white in the woods. The appearance of the robin, bluebird, swallow, the ground hog, and other animals indicated to them various stages in the advent and progress of spring.

[1] In this connection I desire to acknowledge the valuable assistance of the Office of Farm Management, through Mr. O. E. Baker, in supplying data on wheat seeding and harvest dates; to Mr. Baker and Dr. C. F. Brooks, formerly of that office, to Dr. C. E. Leighty of the Bureau of Plant Industry and Prof. J. Warren Smith of the Weather Bureau, for reading the original manuscript and making valuable suggestions on matters relating to their respective branches of the service; also to Mr. Jacob Kotinsky of the Bureau of Entomology for a review of the literature and translations from Russian, German, and French on phenology and other related subjects

Progress of Knowledge.

The progress of a more scientific knowledge of natural guides to practice evidently began with the so-called dawn of science. According to Günther [2] it appears that the Athenians were the first to recognize the relation of plant life events in agriculture to astronomical phenomena and to assign to astronomers the task of correlating such phenomena with weather changes and to tabulate the information in the form of calendars and posters. According to Pliny, Cæsar issued a calendar of periodical events which was used by farmers.

It appears that the progress was slow in the discovery and utilization of natural guides to scientific investigations and economic practice until about the middle of the eighteenth century, when the proposition of Linné for recording observations on the periodical phenomena of plants started the development of the science of phenology. The suggestions of other naturalists led to the recognition of the importance of a knowledge of the natural geographical distribution of plants and animals and the artificial distribution of cultivated plants and domestic animals into the regions to which they were best adapted. The earlier observations on these subjects were for the purpose of recording the facts as they were found without regard to causes and laws of control.

It is of special interest to note that it was the suggestion of Dr. G. H. E. Mühlenberg, of Pennsylvania, and the resultant studies by Dr. Jacob Bigelow,[3] just 100 years ago, that laid the foundation for a most extensive investigation and literature in Europe relating to phenology and the rates of variation in the dates of events with variations in geographical position.

The results of Dr. Bigelow's inquiry and investigations in 1817 as to the dates of flowering of certain plants at various stations between Montreal, Canada, and Fort Clairborne in "Alabama Territory" were published in 1818 [4] under the title "Facts Serving to Show the Comparative Forwardness of the Spring Season in Different Parts of the United States." Dr. Bigelow concluded that "it may be inferred that the difference of season between the northern and southern extremities of the country is not less than two months and a half."

By the middle of the nineteenth century considerable progress had been made in the investigation of periodical phenomena of plants and in the determination of the rates of variation with the variation of latitude, longitude, and altitude, especially as applied to middle Europe.

In 1830 Schubler,[5] guided it appears by the results recorded by Bigelow, discovered that the rate of variation in the dates of certain periodical events between Parma, Italy, and Greifswald, Prussia, was 4 days for about 328 feet of altitude and 1 degree of latitude. In 1846 Quetelet [6] recognized a variation in dates with longitude, but it appears that investigations to determine the rate of difference were not attempted until 1865, when Fritsch [7] concluded that it was about four-tenths of a day for each degree of longitude earlier westward. In 1893 Ihne [8] found that the average difference due to longitude in Europe was about nine-tenths of a day to 1 degree of longitude.

In 1900 the writer [9] arrived at an independent conclusion that for West Virginia there was an average rate of variation of about 4 days to 1 degree of latitude and 400 feet of altitude, and in 1915 [10] he concluded from phenological and other data from different parts of North America north of Mexico that there was a country-wide average variation of about 4 days to 5 degrees of longitude, earlier westward and later eastward from a median point in the continent.

Laws of temperature control.

It was early concluded that the variations in the climate, with temperature as the main factor, was the principal controlling influence of variations in distribution and periodical events under different geographical and physical conditions. Therefore during the past century and a half most exhaustive studies have been concentrated on the subject of temperature in its relation to the growth, periodical phenomena, and the geographical distribution of plants and animals.

Since early in the eighteenth century, [11] and even much earlier, [12] the idea of a sum total of heat required for the development of a plant has received special attention by meteorologists and biologists. This idea of the controlling influence of the sum total of heat during the year and during various periods of development of organisms in the spring and the maturing of seed or fruit in the autumn was developed to an enormous extent, as shown by the number and volume of the publications on the subject in many languages. These investigations resulted in various interpretations of the law of temperature control. None of these proved to be entirely satisfactory as applied specifically to plants and animals, because it was found that different species and varieties respond to the same temperature in a different degree.

The principal objects of investigations relating to the laws of temperature control were to determine reliable guides to agricultural research and practice. The application of these laws of temperature control is necessarily dependent upon the temperature records at stations located at more or less widely separated places throughout the region, country, or continent included in a given line of investigation. The method of procedure is to determine the sum of effective daily temperatures required for the phases or periods of activities of a species

[2] Die Phaenologie, by Dr. S. Günther, 1895.
[3] Rumford professor and lecturer on materia medica and botany in Harvard University.
[4] Memoirs of the American Academy of Arts and Sciences, Vol. IV, part 1.
[5] Flora Regensburg, p. 353, ff.
[6] Ann., Obs. R. Brussels, Vol. V, p. 67, fig.
[7] Sitz, K. Akad. Wiss., Wien, 1866. Vol. LIII, pt. II, p. 264, ffg.
[8] Verh. Ges. Deutscher Naturf. Aerzte. Pt. II, 1st half. Leipzig, 1894 (1893), p. 181, ffg.
[9] Bull. 67, W. Va. Univ. Agricultural Experiment Station, 1900, pp. 242-243.
[10] Program of Work of the United States Department of Agriculture, 1915, p. 232.
[11] Réaumur. Mem. Acad. Sci., 1735, p. 545.
[12] Abbe. Relation between Climate and Crops, Washington, 1905, p. 169.

for the seasons or year by computing from the temperature records of the regions in which the required sum or sums of temperature prevail. The result is then shown on a map by lines connecting the stations with equal sums. This method has been quite extensively used in connection with the discussion of many biological, phenological, and distributional problems. In its broader application the results of these investigations have been of great service as general guides to progress in investigations and practice. Notwithstanding the recognized importance of temperature as a means of interpreting the influences which control the life activities of plants and animals, it has been recognized by many investigators, and especially those engaged in the study of periodical phenomena of species and varieties, that temperature is only one of the elements and factors which characterize the climate of a place, region, or continent. Therefore the influences which control periodical life activities are not to be found in one element alone, but in the fundamental forces and the complex of elements and factors as a whole. The quite early recognition of this fact has led to the consideration and investigation of the solar influence through diffused light and sunshine [13] and to that of rain, snow, humidity, wind, and other phenomena and elements of the atmosphere; also the modification of the influences of these elements under the varying conditions of latitude, longitude, and altitude, all of which has contributed to the further advancement of knowledge of this subject.

Investigations by the Author.

It was through the suggestive work of Dr. Merriam on life zones[14] and with the idea in mind of some other law, in addition to that of temperature control, which might be revealed through a study of the periodic responses of plants and animals to the controlling influences associated with latitude and altitude, that the writer was led to take up this line of research in 1895 in connection with his entomological work at the West Virginia Agricultural Experiment Station.

While the primary object of these investigations has been to solve certain entomological problems, it has not followed that insects alone were utilized as the primary basis. Necessarily the consideration of such a broad subject requires the study of the forms of life which furnish the most conspicuous and constant evidence and at the same time offer the greatest number and variety of fixed objects throughout the seasons of their activity and rest. This is found in forest and shade trees, fruit trees and wild and cultivated shrubs and cultivated crops of the farm and garden. These provide an unlimited supply of material at all times and places and under the influences of varying physical conditions.

Moreover, as the trees and shrubs and farm crops are the hosts of the insects, and the insects are subjected to the same controlling influences as the plants they infest, the plant as the host and the insect as the guest are inseparable in our search for evidence of the natural laws that govern them and for natural guides in the periodical events of the plants to entomological research and practice.

During the period in which these investigations have been in progress the writer has made personal observations in nearly every State in the Union. In addition, extensive records have been made under his instructions at the field stations of the Branch of Forest Entomology of the Bureau of Entomology which have been located for the study of insect problems peculiar to the South Atlantic and Gulf, East Central, New England, Southern Rocky Mountain, Northern Rocky Mountain and Pacific Slope States; also, at intervals, special studies of local conditions and farm crops and farm practice have been made by the writer on his farm near Kanawha Station, West Virginia.

BIOCLIMATIC LAW OF LATITUDE, LONGITUDE AND ALTITUDE.

The results of the investigations by the writer, supplementary to those by other investigators in this and other countries which have a general bearing on the subject of natural guides to agricultural research and practice, led to the conclusions, that:

1. The periodical phenomena of plants and animals are in response to the influence of all of the complex factors and elements of the climate as controlled, primarily, by the motions of the earth and its position relative to the influences of solar radiation.

2. The variations in the climate and consequent variations in the geographical distribution and periodical activities of the plants and animals of a continent are controlled by the modifying influences of topography, oceans, lakes, large rivers, and of other regional and local conditions, and the amount and character of daylight, sunshine, rain, snow, humidity and other elements and factors of a general and local nature.

3. There is a tendency toward a constant rate of variation in the climatic and biological conditions of a continent as a whole in direct proportion to variation in geographical position as defined by the three geographical coordinates, latitude, longitude, and altitude.

4. Other conditions being equal, the variation in the time of occurrence of a given periodical event in life activity in temperate North America is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude and 400 feet of altitude, later northward, eastward and upward in the spring and early summer, and the reverse in late summer and autumn.

[13] According to Abbe, Humboldt insisted upon the necessity of taking the sunlight itself, as such, into consideration in studying the laws of life.

[14] Publications from 1890 to 1894.

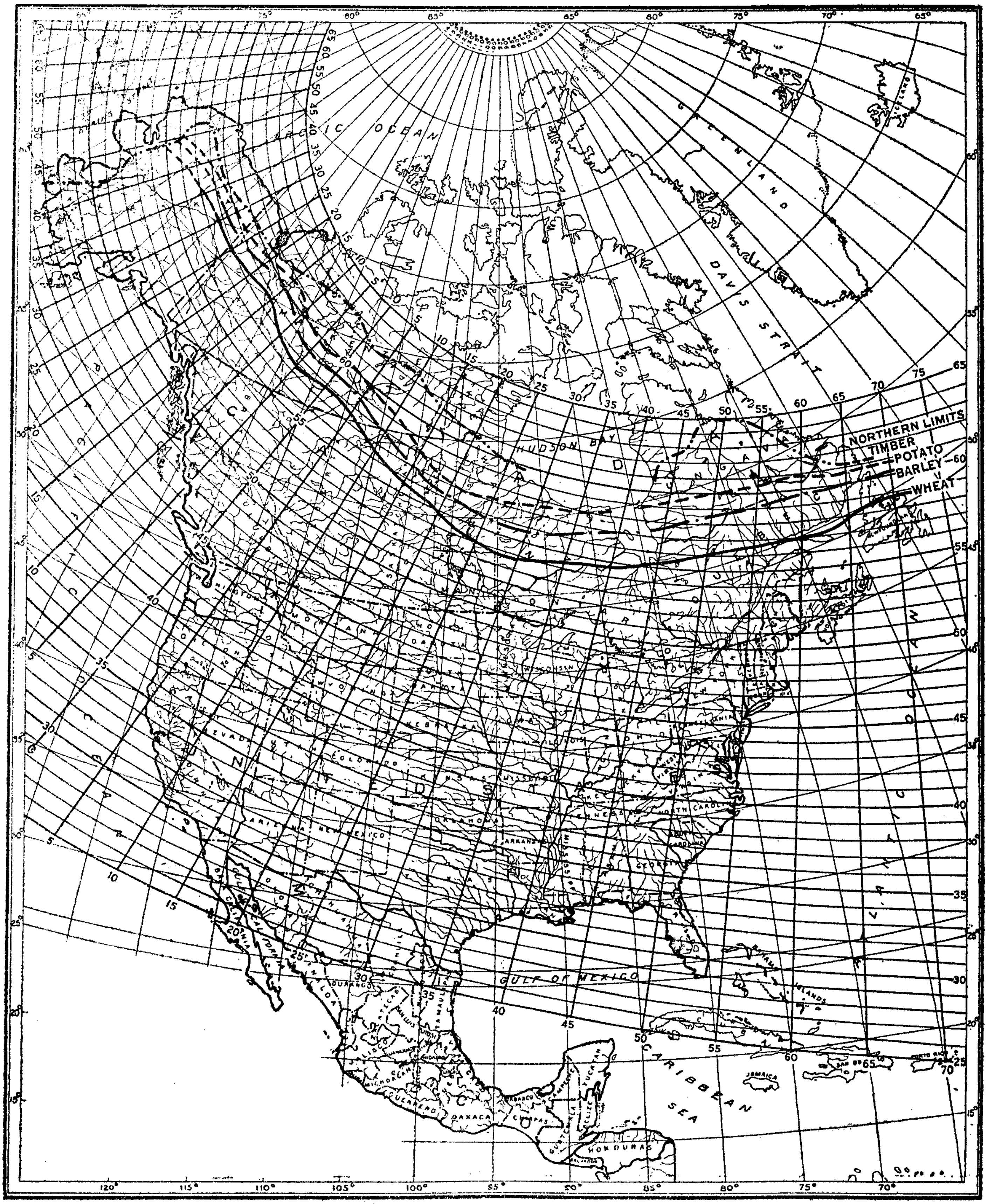


FIG. 1.—Isophanal map of North America in 1-degree isophanes and 5-degree phenological meridians; to show the isophanal-map method of expressing the bio-climatic law. Also showing the relation of the average northern limits of trees and crops.

5. Owing to the fact that all conditions are never exactly equal in two or more biological or climatic regions of the continent, and rarely alike in two or more places within the same region or locality, there are always departures from the theoretical time constant.

6. The departures, in number of days from a theoretical time constant, are in direct relation to the intensity of the controlling influences. Therefore the constant, as expressed in the time coordinates of the law, is a measure of the intensity of the influences. (See figs. 4 to 7.)

The fundamental guide.—From the foregoing it appears that we have in this proposed bioclimatic law of latitude, longitude and altitude, a fundamental guide to lines of research and practice as related to any periodical phenomena in life activity including that of man.

The recognition of this law, together with the determination of phenological constants as a basis for measuring departures due to regional and local influences has served as a guide to continued investigations by the writer and to the discovery of many supplementary guides and methods which are applicable to a wide range of scientific and economic subjects and problems.

The results of the more recent investigations discussed in the following pages, including a comprehensive study and comparison of well-known facts of geographical distribution of plants and animals and those determined by phenological observations together with the conclusions as to the rates of variation in dates of periodical events with variation in geographical positions, as recorded in literature and observed by the writer, have furnished sufficient evidence to establish the bioclimatic law as a reliable guide and working basis.

SYSTEMS OF APPLICATION OF THE LAW IN RESEARCH AND PRACTICE.

The more recent investigations by the writer have been with the object of developing systems of applying the law in research and practice. It is believed that this has been accomplished in the development of a system of maps and computing calendars and tables which, in addition to simplicity and economy in use, furnish—in the examples given—further evidences in support of the law and its practical application.

Elements of the system.

The elements of the system may be briefly described as follows:

(1) *The isophanal maps.*—Taking base maps of North America and of the major and minor political divisions, parallel lines (designated as *isophanes*) are drawn on them to define, according to the bioclimatic law, theoretical lines and zones of equal phenomena as to time of occurrence and equal bioclimatic conditions, at the same level. These isophanes may represent any desired interval of latitude to correspond to the time constant, from one-fourth of a degree and one day to 5 degrees and 20 days. Longitudinal lines, designated as phenological meridians or pheno-meridians, are also drawn on the maps at approximately right angles to the isophanes to represent intervals of 1 degree to 5 degrees or more of longitude (see figs. 1 and 2).

The isophanes, instead of following the parallels of north latitude in North America, proceed from the Atlantic to the Pacific in a northwestward curve at the rate of 1 degree of latitude to 5 degrees of longitude (fig. 1), so that they serve as a diagrammatic expression of the average rate of four days variation for 1 degree of latitude and 5 degrees of longitude. Therefore one of these lines across the continent at any given level of land surface represents, cæteris paribus, the same average phenological constant date of a seasonal event and the same average climatic and biological conditions.

The phenological meridians serve to locate the geographical position of places on or near the isophanes and to define major and minor quadrangles as areas and centers for biological and phenological observations and comparison. They are drawn at intervals to represent 1 degree or more of longitude according to the intervals of the isophanes on the map to which they are applied at the rate of 5 to 1.

Numeral designations for the 1-degree isophanes are adopted to correspond to the number of the parallel of latitude crossed by them on the one-hundredth meridian of longitude (fig. 1). The one-fourth degree isophanes are designated by the number of the isophane and small letters *a*, *b*, and *c*, as in figure 2. The phenological meridians are designated by numbers for each 1-degree meridian, beginning with zero on the 125th meridian of longitude and running east to the Atlantic coast and from zero west to the extreme western coast of Alaska (fig. 1). Thus it is necessary to distinguish the eastern meridians from the western ones, where both are under consideration, by the suffix of E or W to the meridian number.

(2) *The map calendar.*—The map calendar is a fixed part of the map and gives the dates of a given event computed from a single base for the various altitudes to be found along the course of the isophanes on the map as in figures 8, 9, and 10. For further descriptions of map calendars, their construction and examples of application, see pages 23, 31, etc.

(3) *The adjustable and computing calendars and tables.*—The adjustable and computing calendars are separate from the map, hence may be constructed with computed dates from any given base or for any subject. They are constructed on the same principle as the map calendar but differ in that any number of them, representing different bases and subjects, may be prepared and adjusted to the same map, or may be used without a map if a list of the localities with their isophanal and altitudinal designations is given. The blanks for adjustable calendars can also be used for computing dates, periods, or altitude levels from any given base and for

the isophanes and altitudes of any given area or region. For further descriptions and examples of application see pages 33 to 35 and the tables, figures 13 to 23, inclusive.

(4) *The altitude-limit table.*—The altitude-limit table differs from the map and adjustable calendars in having the standard altitudes in the second longitudinal space of the calendar blank on the isophanal lines at intervals of 400 feet to correspond to the intervals of the 1-degree isophanes of the map. For further description and examples of application see page 24 and Table 3.

Similar tables can be devised for computed annual or seasonal means of temperature, sums of effective temperature, etc.

geographical position either by latitude and longitude or by the isophanes. It has been found in practice, however, that computation by the adjustable calendar and table methods is more direct and convenient.

Applications of the system.

With the isophanal maps prepared in the manner described and with the computing calendars and tables we have a simple system by which the dates and periods of any periodical event, periodical practice or geographical limit of a species or practice can be computed from any given base for any other geographical position.

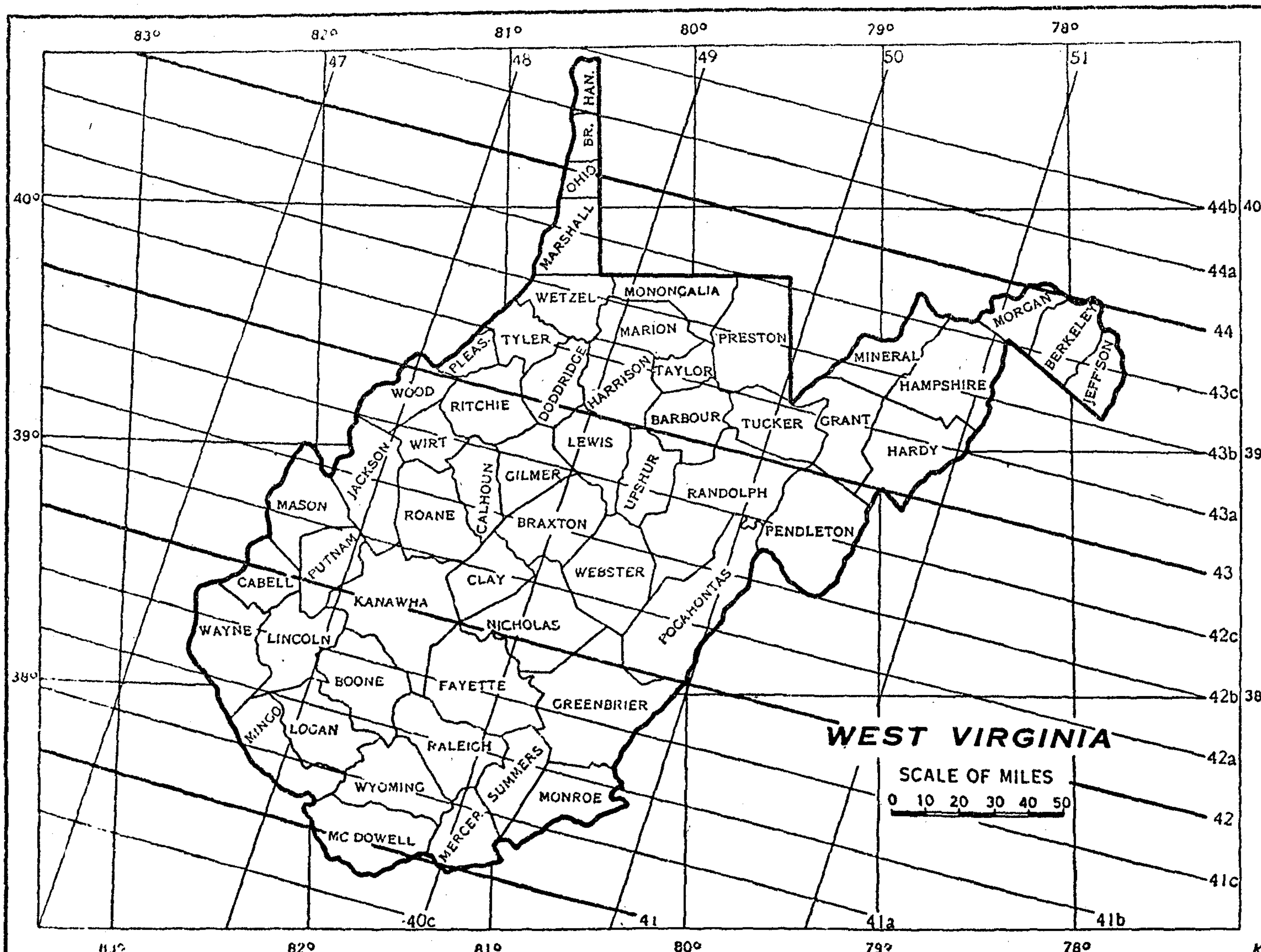


FIG. 2.—Isophanal map of West Virginia in ¼-degree × 1-degree quadrangles; to show the method of numbering the ¼-degree isophanes and the 1-degree phenological meridians.

(5) *Phenological disk calendar.*—Several methods facilitating the computation of data have been devised, including a phenological calendar (fig. 24, p. 42), which consists of adjustable disks with numbers representing month and year dates, latitudes, longitudes, and altitudes, all at the standard intervals of the time coordinate of four days. By means of this computing calendar the date to correspond to that of a base is found for any

Isophanal map of North America.—The isophanal map of North America north of Mexico (fig. 1) represents 1-degree isophanes from 26 to 65 and 5-degree phenological meridians from 0 to 75 E. and 0 to 65 W. which form 1- × 5-degree quadrangles for the entire land surface.*

*Through inadvertence the meridians in the northeast and northwest portions of the map, figure 1, were not continued at right angles to the isophanes of those portions. The error was discovered too late to be corrected.—*A. D. H.*

It will be noted that with the converging meridians of longitude the northwestward curve of the isophanes increases rapidly from east to west while the phenological meridians converge toward a central line which passes through the region of the magnetic pole. As to whether or not the general converging of the meridians toward a center represented by the magnetic pole is a coincidence or is in conformity with a fundamental law, the writer will not even offer an opinion in this connection. It is a question for the physiographer and astronomer to answer.

The northwestward trend of the isophanes—The advance of spring in the east and west.—As an example of the application of the system to the investigation of evidence west is found in the fact that, upon comparing the time of the advent of spring in southern Florida and the character of the subtropical vegetation with that of southern Arizona and southern California, it is found that, allowing for the retarding influences in eastern Texas[15] and the high elevations of western Texas, southern New Mexico and Arizona, the line marking the progress of spring will coincide with isophane 30 much more nearly than with the 26th parallel of latitude west from Florida. It is also found that the general types of subtropical vegetation prevail in California 7 degrees north of the area of similar conditions in Florida. Going farther north we find that the advent of spring in latitude 39 along the Atlantic coast more nearly coincides

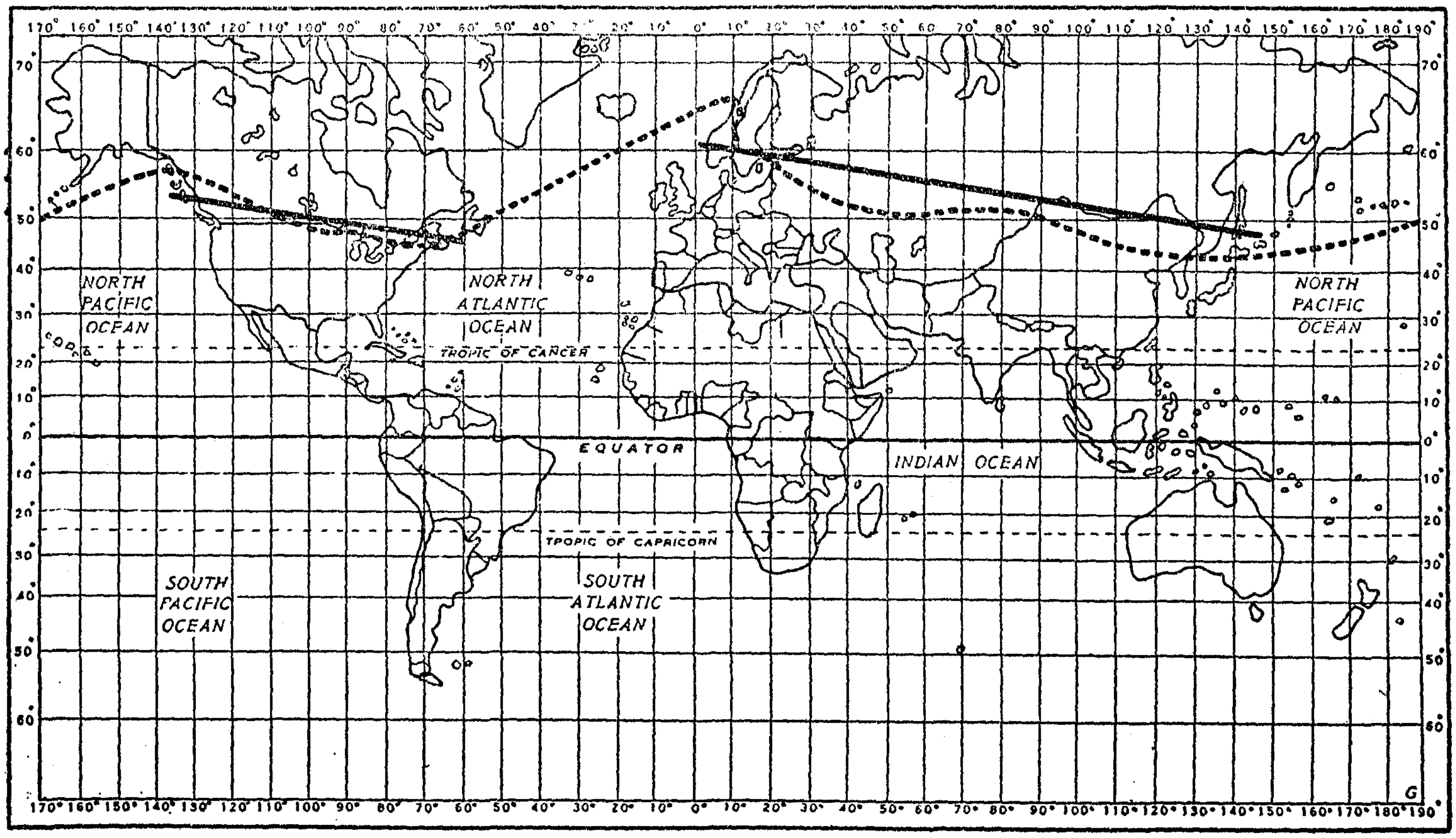


FIG. 3.—Map of the world on Mercator projection, showing the relation of the average annual isotherm through Sitka to the isophanes in the eastern and western continents of the Northern Hemisphere. (Isotherm interpolated from Bartholomew's Atlas, Plate I.)

in support of the theory of a bioclimatic law, as expressed in the isophanes, we will take the isophanal map of North America (fig. 1) and compare the northwestern trend of the isophanes with the advance of spring in the eastern and western half of North America north of the 26th parallel; also with the progressive variations in the climate as indicated by the progressive changes in the character of plant and animal life from the subtropical conditions in southern Florida and California to the Arctic region.

Evidence that the progress of spring in the western part of North America is in advance of that in the east and that the progress is somewhat more rapid in the in time with that toward the Pacific coast in latitude 48 than with that toward the Pacific coast in latitude 39, and again, allowing for the retarding influences of the Mississippi Basin and Rocky Mountains, the general line of progress across the country coincides with the isophanes and widely departs from the parallels of latitude, so that the advent of spring toward the Pacific coast, as compared with that toward the Atlantic, shows an advance in the west of about 9 degrees farther north. As we proceed northward the force of the evidence increases for we find that by the time spring has advanced in the east to latitude 50 it has advanced to near the Arctic

[15] *See* Evidence of bioclimatic regions, p. 19 and fig. 5.

Circle in Alaska. This is shown particularly in the northern progress of the migration of certain birds, such as the bank swallow.

Furthermore, when the transcontinental isotherm for April to July, inclusive, is compared with the isophane 43 and 38th parallel of latitude it is found that it follows far more closely the isophane than the parallel of latitude. The annual isotherm which passes through Portland, Me., and Sitka, Alaska, closely parallels isophane 49 and, when we follow the course of this isotherm around the world (fig. 3), we find that it descends across the Pacific to Japan and that from northern Korea it maintains a northwestward course to near the Arctic Circle in Norway, so that on the eastern continent it is more than 20° of latitude farther north in the west than in the east. This indicates that the same or similar northwestward trend of lines of equal conditions prevails in the northern Temperate regions of both the western and eastern continents.

Figure 4 is based on the averages of the reported dates of the beginning of winter-wheat harvest (July 2, altitude 1,000 feet, at Wooster, Ohio, as explained on pp. 14 and 29) and is constructed to correspond to the latitudes, longitudes, and isophanes of an isophanal map so far as straight lines will permit. The upper horizontal line represents latitude 48, the lower one latitude 38, and the line running from the southeast to the northwest corner represents isophane 43. The vertical lines represent phenological meridians at intervals of five degrees with their numbers above the latitude line. The oblique lines represent longitudes at the same intervals with their numbers below the latitudinal line. The curved lines represent the broad average plus and minus departures of the average reported dates from the computed constant dates of the beginning of wheat harvest between isophanes 43 and 44 and also the departures from the dates between latitudes 38 and 39, computed from the same base for the various average altitudes throughout the length of the isophane and latitude across the country. The isotherm for June, July, and August is also shown. It will be noted that from east to west there is a more or less marked average minus (earlier) departure from latitude 38, while the departures from the isophane are both minus (above) and plus (below), with the isophanal line representing the general average of all departures. This shows clearly that going west there is a constant early departure from the latitude reaching its maximum in the Rocky Mountains and that the isophane represents the average course of the departure for latitude, isophane, and isotherm; thus furnishing quite conclusive evidence in support of the time coordinate of variation for longitude, and that the climatic conditions which influence the time of wheat harvest are far more nearly equal along the isophane than along the parallels of latitude.

The broad divergence of the average lines in the west is due to the different rate of departure between the area represented by latitude 38 and that represented by isophane 43, within a range of from five to 10 degrees of latitude; otherwise, both the lines of average departure would more nearly approximate the isotherm, as they do between about longitude 87° to 102°.

Northern limits of geographical distribution of plants and animals.—It is in the northern limits of the distribution of species of plants and animals in North America, including cultivated crops, that we find the most forcible and convincing evidence that the isophanes represent far more nearly lines of equal biological and climatic conditions across the continent than do the parallels of latitude.

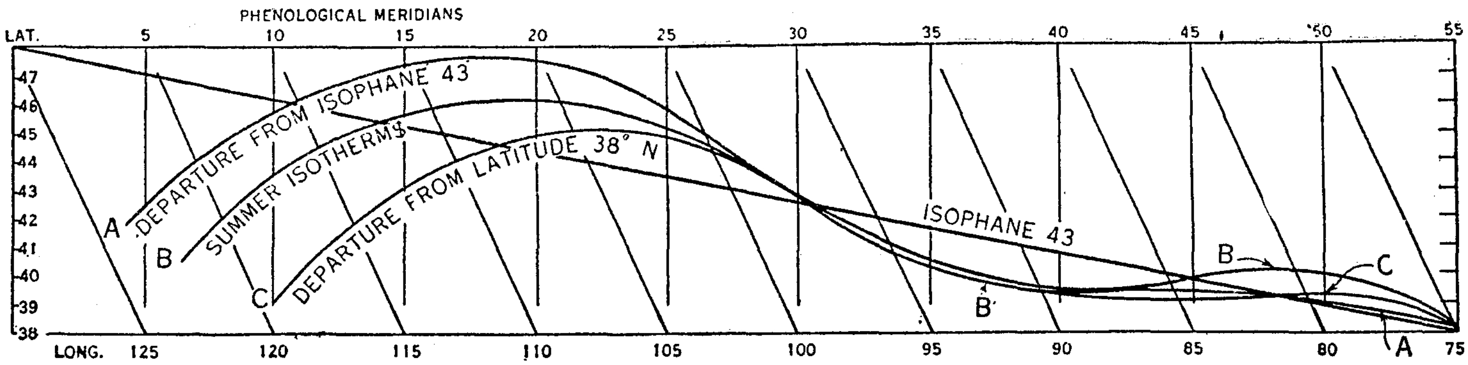


FIG. 4.—Diagram illustrating the average earlier departures from the isophanal and latitudinal constants.

On figure 1 the writer has traced, from reliable sources, composite lines representing the approximate average northern limits of timber and a few cultivated crops. It will be noted that they parallel the general course of the isophanes in a most striking manner.

When we consider all of this evidence with a full recognition of the modifying influences of the Pacific and Atlantic Oceans with their warm and cold currents, and of the Rocky Mountain and Appalachian plateaus, the Great Plains, the Mississippi Basin, Great Lakes, and Hudson Bay, and the further modification associated with the humidity of the eastern half of the country and of the Pacific Slope and the aridity of the southwestern United States, we find that there are conflicting influences favoring and opposing the maintenance of equal conditions along the isophanes. Notwithstanding these conflicting influences, there remains a persistent countrywide northwestward trend of equal bioclimatic conditions. This indicates that there are fundamental terrestrial influences and solar forces which are more powerful in shaping and maintaining the general northwestward course of equal conditions than are all of the other opposing influences toward changing it. More specific evidence will be found in the examples of isophanal maps and adjustable calendars for winter and spring wheat and the data on which they are based.

Evidence as related to the altitude coordinate.—Little argument is required to show that the rate of variation in climatic and biological conditions, under the influence of increasing altitude, is in the same ratio as that with increasing latitude northward, for it has been generally recognized that such a corresponding relation exists. This is forcibly shown in the case of high mountains rising above low valleys or sea level in a tropical or subtropical region where, within a distance of a few miles, all the climatic and biological conditions are found, from tropical at the base to arctic at the summit. The rate of this progressive change from tropical to arctic conditions as expressed in the average number of days between the dates of the first manifestation of spring at a low level and the same manifestation at a high level, has been determined so often that, even with the slightly varying results, due in most cases perhaps to difference in regional and local influences (fig. 6), it may be considered as established that, other things being equal, the general average is at the rate of one day to 100 feet, or the adopted unit of 4 days to 400 feet.

Altitudinal and isophanal time coordinates as a measure of distance.—Assuming that, other things being equal, the altitudinal and isophanal time coordinate rate of 4 days variation in the dates of periodical events with variation in geographical position is in direct proportion to the rate of variation in climatic and biological conditions, then the 4-day coordinate serves not only as a measure of time between events at two or more places but also as a measure of distance in latitude and altitude required for equal climatic and biological conditions. Thus the same climatic and biological conditions that prevail at the 3,600-foot level on isophane 43 in West Virginia should be found at sea level, 9 degrees of latitude farther north on isophane 52 (fig. 7), because the difference in altitude is balanced by the difference in latitude as represented by the isophanes. In other words, taking a place at the 3,600-foot level on isophane 43 as the base, with April 1 as the determined date of a spring event, the place farther north at sealevel where the same conditions and date should occur for the same event would be (3,600 ÷ 400 feet =) 9 coordinate time units which are equal to 9 one-degree isophanes. Therefore, since 9 isophanes + isophane 43 = 52, the theoretical position where the conditions and dates should be equal to those of the base would be at sealevel on isophane 52. Thus the distance from the base, as measured by the time coordinate, is 9 degrees of latitude farther north and 3,600 feet lower.

In a like manner, the climatic and biological conditions and the altitude and latitude range and limits of species, varieties, crops, dates of periodical events in plants and in farm operations, can be approximately determined for any geographical position within a climatic or biological region and, with corrections for regional influences, they can be made to very closely approach the actual.

With the isophanes as a guide to the place of equal conditions and events at any given level it is a simple matter to determine the corresponding average conditions and dates which, other things being equal, should be found at different levels on each isophane (fig. 5).

This result can be obtained by direct mathematical computation or by means of computing calendars and tables.

Method of Computation.

The determined base.—The first requisite in computing dates, or altitude limits, etc., is a determined base where the dates have been established by observations, experiments, or practice for a sufficient number of years to establish a reliable average.

Computing from the base.—Taking the area represented by Wooster, Ohio, as the determined base for average dates of winter wheat seeding and harvest, the base is expressed as follows:

(1) Wheat seeding general, September 20, isophane 44b, altitude 1,000 feet above the sea.

(2) Wheat harvest begins July 2, isophane 44b, altitude 1,000 feet.

1. The corresponding date for the beginning of wheat harvest on isophane 44b, altitude 3,000 feet would be (3,000 − 1,000 feet = 2,000 feet ÷ 100 feet to 1 day = 20 days later and July 2 + 20 days =)July 22.

The date on isophane 34b, altitude 1,000 feet would be (isophane 44b − isophane 34b = 10 one-degree isophanes; 10 isophanes × 4 (days to the isophane) = 40 days earlier; July 2 − 40 =)May 23.

The date on isophane 34b, altitude 3,000 feet, would be: (isophane 44b − 34b = 10 × 4 = 40 days earlier, and 3,000 − 1,000 = 2,000, 2,000 ÷ 100 = 20 days later; 40 days early − 20 days later = 20 days earlier and July 2 − 20 days =) June 12.

2. The date for seeding on isophane 44b, altitude 3,000 feet, would be: (3,000 − 1,000 = 2,000, 2,000 ÷ 100 = 20 days earlier and September 20 − 20 days =) August 30.

The date on isophane 34b, altitude 1,000 feet, would be: (isophane 44b − 34b = 10 isophanes × 4 = 40 days later, and September 20 + 40 days =) October 29.

The date on isophane 34b, altitude 3,000 feet, would be: (isophane 44b − 34b = 10 × 4 = 40 days later, and 3,000 − 1,000 = 2,000, 2,000 ÷ 100 = 20 days earlier; 40 − 20 = 20 days later and September 20 + 20 =) October 10, and so on for any combination of isophane and altitude.

This method of computing was found to require too much time where large numbers of places were involved, therefore the phenological calendar (fig. 24) was devised in 1915 to be followed in 1917 by the computing calendars and tables by which the desired results are obtained in a more rapid and economical manner, as shown in the tables of figures 13, 18–23.

APPLICATION IN THE INVESTIGATION OF SEEDING AND HARVESTING DATES FOR WINTER WHEAT.

The seeding and harvesting dates for winter wheat, as reported by growers from all of the States and practically all of the counties in the entire country where winter wheat is grown as an important product of the farm, have served as the best available examples of the application of the law to a study of the rates of variation in dates north, south, east, and west, and at different levels from a determined base.

Through the courtesy of Mr. O. E. Baker, of the Office of Farm Management, over 40,000 reports from farmers on the average dates of the beginning, general, and latest dates of seeding and harvesting winter wheat that had been secured in 1914 by the Bureau of Crop Estimates and compiled on large State maps by the Office of Farm Management, were made available to the writer.

The computed average or median dates and altitudes for each county were given on the maps for the counties from which more than one report had been received. Thus an abundance of data already compiled was made available for the investigation of two important periodical events: (1) A generally recognized natural event in the ripening of grain; (2) a farm practice.

The beginning of wheat harvest is a definite periodical event of common recognition, the time of occurrence of which at different localities is controlled by continental, regional, and local influences of climate, weather, and other factors and elements which affect the development of the plant.

The average date of seeding is a less definite event which is controlled in a broad way by the same influences as those which control the date of harvest, but is more or less extensively modified by the local experience, custom and convenience of the growers of each community.

The reported dates of the average beginning of harvest furnished the most reliable basis for comparing the average of the reported dates with those computed according to the bioclimatic law, for counties and larger areas of a State. At the same time they furnished a reliable guide to the determination of the rates of earlier or later departures for regions and areas.

Methods of procedure.—Owing to the special studies made by Webster at Wooster, Ohio, relating to the seasonal history of the Hessian fly and his determination of the average safe date to sow wheat to escape its attack, this locality was adopted as the base from which to compute the comparative average dates for the seeding and harvesting of wheat for all other localities and areas.

The determined safest and best date for seeding in the ½ × 1-degree quadrangle represented by t is base is September 20 and the average altitude 1,000 feet. The geographical position of this base is represented by isophane 44b and phenological meridian 47, therefore the base is expressed as follows: Isophane 44b, phenomeridian 47, altitude 1,000 feet, date September 2 0.

The method of procedure in the study of the data was to make an isophanal map of the State under consideration as in figure 2 (West Virginia), in ½-degree isophanes and 1-degree phenological meridians. This gave ½ × 1-degree quadrangles in which parts of one or more counties were represented.

The average dates and altitude for each quadrangle were computed from the averages of the reported dates for the counties represented in the quadrangle by about one-fourth or more of their area. The average of the reported altitudes was also verified or supplied from other sources, contour maps, etc. The theoretical dates for the altitudes and quadrangles were then computed from the base and the difference between the reported and theoretical dates determined. All of these data were then tabulated for each State as in Table 1.

The numeral designations of the isophanes and meridians served to define and distinguish each quadrangle as a phenological unit area for comparison with the Wooster base unit. The quadrangle is defined by the isophane to the south and the meridian to the west of the center. Thus, as given in Table 1, isophane 44a (column 1), meridian 48 (column 2) and average altitude 1,000 feet (column 3), including Hancock Co., W. Va,, with an average reported harvest date of July 3 (column 4) and the computed date July 1 (column 5) with a plus departure of 2 days (column 6), shows that the reported date was two days later than the computed date.

The reported general average seeding date for the same county was September 15 (column 4 under seeding) and the computed date is September 21, giving a minus or earlier departure of 6 days from the computed date.

In this manner tables were worked out for all of the States but Florida and Louisiana.

Method of tabulating the data.—All data were tabulated as in Table 1A. The departures of the reported from the computed dates were tabulated for the same altitudes on each isophane represented (Table 1B), for the average of each altitude (Table 1C), and the averages for all altitudes and the State (Table 1D). In addition to the average departures for the altitudes of each State, averages were computed for 1×1, 1×5 and 5×5 quadrangle units for the United States.

A study of these results demonstrated the known superior value of the departure over the dates as a basis for interpreting regional and local influences in retarding or accelerating the events. They are also to be preferred as a guide to the required positive or negative corrections to the computed dates. A study of the tables shows that in general, where there was no evidence of a prevailing influence tending to retard or accelerate, there was but a slight variation between the reported and computed dates for the beginning of harvest, thus giving substantial support to the law as a reliable guide for forecasting dates of periodical events and bioclimatic conditions for any given quadrangle unit.

Comparison of the averages of reported with computed dates for harvesting and seeding winter wheat in West Virginia.

The table of comparisons of the averages of the reported and computed dates of harvesting and seeding for the quadrangles in West Virginia (Table 1A) is given here as an example of the method of compiling the data.

TABLE 1-A.—*Comparison of averages of reported with computed dates for harvesting and seeding winter wheat in West Virginia.*

[See below for explanation.]

Isophane.	Phenological meridian.	Altitude.	Beginning of harvest.				General seeding.			
1	2	3	4	5	6	7	4	5	6	7
		Feet.								
44a	48	1,000	7.3	7.1	+2	......	9.15	9.21	......	−6
44	51	500	6.22	6.25	......	−3	10.1	9.27	+ 4	......
	48	1,000	7.2	6.30	+2	......	9.20	9.22	......	−2
43c	51	500	6.22	6.24	......	−2	10.1	9.28	+ 3	......
	50	600	6.24	6.25	......	−1	10.1	9.27	+ 4	......
	48	1,000	7.1	6.29	+2	......	9.20	9.23	......	−3
43b	51	600	6.24	6.24	0	0	10.1	9.28	+ 3	......
	50	1,000	6.25	6.28	......	−3	10.1	9.24	+ 7	......
	49	2,000	7.5	7.8	......	−3	9.16	9.14	+ 2	......
	48	1,000	6.28	6.28	0	0	9.30	9.24	+ 6	......
43a	50	1,000	6.25	6.27	......	−2	10.1	9.25	+ 6	......
	49	2,200	7.6	7.9	......	−3	9.15	9.13	+ 2	......
	48	1,000	6.27	6.27	0	0	10.1	9.25	+ 6	......
43	50	1,800	6.25	7.4	......	−9	10.1	9.18	+13	......
	49	2,000	6.28	7.6	......	−8	10.1	9.16	+15	......
	48	800	6.25	6.24	+1	......	10.2	9.28	+ 4	......
42c	50	2,000	6.29	7.5	......	−6	9.29	9.17	+12	......
	49	1,000	6.25	6.25	0	0	9.27	9.27	0	0
	48	800	6.25	6.23	+2	......	9.28	9.29	......	−1
	47	800	6.25	6.23	+2	......	10.5	9.29	+ 6	......
42b	50	2,000	6.28	7.4	......	−6	9.28	9.18	+10	......
	49	1,400	6.20	6.28	......	−8	10.1	9.24	+ 7	......
	48	1,000	6.20	6.24	......	−4	9.28	9.28	0	0
	47	800	6.20	6.22	......	−2	9.28	9.30	......	−2
42a	49	2,400	7.3	7.7	......	−4	9.30	9.15	+15	......
	48	1,000	6.20	6.23	......	−3	10.5	9.29	+ 6	......
	47	700	6.20	6.20	0	0	10.10	10.2	+ 8	......
42	49	2,400	7.3	7.6	......	−3	9.30	9.16	+14	......
	48	1,400	6.27	6.26	+1	......	10.8	9.26	+12	......
	47	700	6.20	6.19	+1	......	10.5	10.3	+ 2	......
41c	49	2,000	6.29	7.1	......	−2	9.28	9.21	+ 7	......
	48	800	6.20	6.19	+1	......	10.5	10.3	+ 2	......
	47	700	6.17	6.18	......	−1	10.1	10.4	......	−3
41b	49	2,000	6.28	6.30	......	−2	10.1	9.22	+ 9	......
	48	1,000	6.18	6.20	......	−2	10.5	10.2	+ 3	......
	47	1,000	6.17	6.20	......	−3	10.1	10.2	......	−1
41a	49	1,400	6.25	6.23	+2	......	10.4	9.29	+ 5	......
41	49	2,000	6.28	6.28	0	0	9.25	9.24	+ 1	......

TABLE 1-B.—*Average departures of reported from computed dates of beginning of harvest.*

[See p. 16 for explanation.]

Isophane.	Feet above sealevel.																			
	500		600		700		800		1,000		1,400		1,800		2,000		2,200		2,400	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
44a									2											
44		3							2											
43c		2		1					2											
43b			0	0						1.5						3				
43a										1								3		
43							1							9		8				
42c							2		0	0						6				
42b								2		4		8				6				
42a					0	0				3										4
42					1						1									3
41c						1	1									2				
41b										2.5						2				
41a											2									
41															0	0				
General averages	−2.5		−0.5		0.0		+0.5		−0.6		−1.6		−9		−3.8		−3		−3.5	

TABLE 1-C.—*Average departures of reported from computed dates of general seeding.*

[See p. 16 for explanation.]

Isophane.	Feet above sealevel.																			
	500		600		700		800		1,000		1,400		1,800		2,000		2, 00		2,400	
	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
44a										6										
44	4									2										
43c	3		4							3										
43b			3						6.5						2					
43a									6								2			
43							4						13		15					
42c							2.5		0	0					12					
42b								2	0	0	7				10		[illegible]			
42a					8				6										15	
42					2						12								14	
41c						3	2								7					
41b									1						9					
41a											5									
41															1					
General averages	+3.5		+3.5		+2.3		+1.6		+0.9		+8		+13		+8		+2		+14.5	

TABLE 1-D.—*Comparison of average departures for altitudes and for the State.*

[See p. 16 for explanation.]

Altitude.	Beginning of harvest.		General seeding.		Corrected departures for general seeding.	
	+	−	+	−	+	−
Feet.						
500	......	a2.5	3.5	......	1	......
600	......	0.5	3.5	......	3	......
700	0	0	2.3	......	2.3	......
800	0.5	......	1.6	......	2.1	......
1,000	......	0.7	0.9	......	0.2	......
1,400	......	1.6	8	......	6.4	......
2,800	......	9	13	......	4	......
2,000	......	3.8	8	......	4.2	......
2,200	......	3	2	......	......	1
1,400	......	3.5	14.5	......	11	......
General average	b−2.4		+5.6		+3.2	

a Average for the 500-foot level. b Average of all levels.

Explanation of Table 1A.—Column 1 gives the numeral designations of the isophanes beginning with the one farthest north (44a). Those with the suffix of a small letter are for the ¼-degree isophanes and those without the suffix are for the 1-degree isophanes.

Column 2 gives the numeral designations of the phenological meridians beginning with the one farthest east (51). Thus (34a, 51) define the ¼ × 1-degree quadrangle for which the computations of reported and computed averages are made.

Column 3 gives the average altitude of the quadrangle on which the computed average is based. While in most cases the altitude was reported with the dates, many of them quite accurately, more dependence was placed on an estimate of the average from State and United States topographic maps.

Column 4 gives the average of the reported dates for the counties represented in the quadrangle. While many, if not most, of the reported dates are based on a guess or an estimate and some of them given too early and others too late, it is believed that the general average comes about as near to the correct average date for all seasons as it is possible to get them from correspondents.

Column 5 gives the computed average dates for the quadrangles and average altitudes.

Column 6 gives the plus, or later, departure of the reported average date from the computed average date in days.

Column 7 is the minus or earlier departure of the reported from the computed.

Columns 4 to 6 under seeding are respectively reported, computed, plus, and minus as for harvest.

Departure of reported from computed dates for beginning of harvest.—The average departures for altitudes are (Table 1B) for all isophanes and quadrangles with the average as given in the altitude column or, in other words, for all of the given average levels for each isophane across the State.

The table shows that for the beginning of wheat harvest there is a minus departure for practically all altitudes. That is, the average date for the beginning of harvest throughout the State, giving all altitudes equal weight, is 2.4 days earlier than the computed average, with a range from 0 to 9 days.

Average departures for general wheat seeding.—It will be noted (Table 1C) that the average general date for seeding is later than the computed date, with an average for the State of 5.6 days later and a general range from 0 to 15 days, and a range in the averages for each given altitude of from 0.9 to 14.5 days later than the computed average. This generally later date than the computed safe or fly-free date is significant from the fact that practically no damage has been reported from the Hessian fly since the writer's wheat seeding calendar map was issued for the State in 1900, although for several years previous to that time serious losses were reported from all sections of the State. In fact, it would appear that a habit of sowing late has been formed by wheat growers, specially at the higher altitudes.

Since these computations of averages and departures are based on the reported dates of general seeding, it is plainly seen that much of it is sown too late as compared with the theoretical best date.

Since there is a general early departure of the dates for beginning of wheat harvest from the computed dates, it is evident that there is a prevailing influence in the State which contributes to an accelerated or earlier departure averaging 2.4 days which is equivalent to more than ½ degree south, or an average of about 200 feet lower. It would appear, therefore, that the computed seeding dates should be corrected to a later date to compensate for a retarding influence equal to ½ degree south, or 200 feet lower level. But, since this requires further investigations and the departure is less than four days, the map calendar for the State is based on the constant dates.

In case it is desired to make such corrections the minus departure for the spring event of harvest is subtracted from the computed date for seeding. In the case of a positive departure, which is equivalent to a higher latitude or altitude, the amount of the departure is added to the computed date for seeding.

Thus, since the average departure in the harvest date for 500 feet in ¼×1 quadrangle, 44×51, is −3 days and the computed date for this quadrangle is September 27, the corrected date would be September 27+3 days, giving September 30 as the corrected date; while for the ¼×1 degree quadrangle, 44a×48, altitude 1,000 feet, with September 21 as the computed date and a plus departure of 2 days, the computed date would be corrected by subtracting 2 days, giving September 19 as the corrected date. It is more accurate to utilize the departures for 1×1 quadrangles which are determined by computing the average dates and altitudes for the ¼×1-degree quadrangles, as 42, 42a, 42b, and 42c, between phenologic meridians 48 and 49. Thus, if the average departure for the 1×1-degree quadrangles, 42×48, 1,000 feet, is −1 day for harvest and the average computed seeding date for this quadrangle is September 28, the corrected date would be 28+1=September 29.

Comparisons of average harvest and seeding departures for altitudes and the State.—In comparing the average departures from the computed dates (Table 1D) it will be noted that practically all of the reported harvest dates are earlier than the computed dates, and that the reported seeding dates are later. Now, to determine how much later the reported seeding dates are than the computed seeding dates by the method just described, it is necessary only to subtract the minus for harvest from the plus for seeding, or add the plus for harvest to the plus for seeding, as in the example given under corrected departures (Table 1D.) Thus it will be seen that even after making these corrections the average reported dates are still safe and practically all of them are within the range of the best period.

The isophanal map of West Virginia (fig. 2), together with Table 1, will serve as examples to illustrate the method of investigating the periodical events of harvesting and seeding winter wheat and the map-calendar of wheat seeding dates (fig. 9), discussed further on, will serve as an example of the method of making the results of such investigations immediately available in practice.

Figures 5 and 6 will show the relations of elevations, depressions, and slopes to plus and minus departures, and figure 7 will show the relation of altitude and latitude to the time gradients and all will illustrate graphically methods of expressing and interpreting the law.

Summary of departures in the dates of the beginning of wheat harvest in the United States.

When the tabulation of the data for all of the States was completed, after the manner shown in Tables 1A to 1D, the departures for the beginning of wheat harvest were summarized and the average computed for 1×5- and 5×5-degree quadrangles for all that portion of the United States covered by the reports. Averages for the individual States were also computed. The results were then transferred to isophanal maps, as shown in the maps (figs. 10, 11, and 14).

A study of the maps and figures 4 to 7 revealed some exceedingly interesting evidence and guides relating to the principle of departures and the regions of the United States in which general accelerating and retarding influences prevail, as affecting the ripening of wheat.

should expect to find the timber line at 8,200 feet because of the general plus departure of 8 days which would reduce it by that much. In a like manner, we should expect to find timber line at about 9,600 feet on the highest peaks of the Uinta Mountains (*k*) and at 8,600 feet on a mountain in southern Oregon.

Line *c* represents the average constant altitude for the highest limit of profitable winter wheat culture (table in

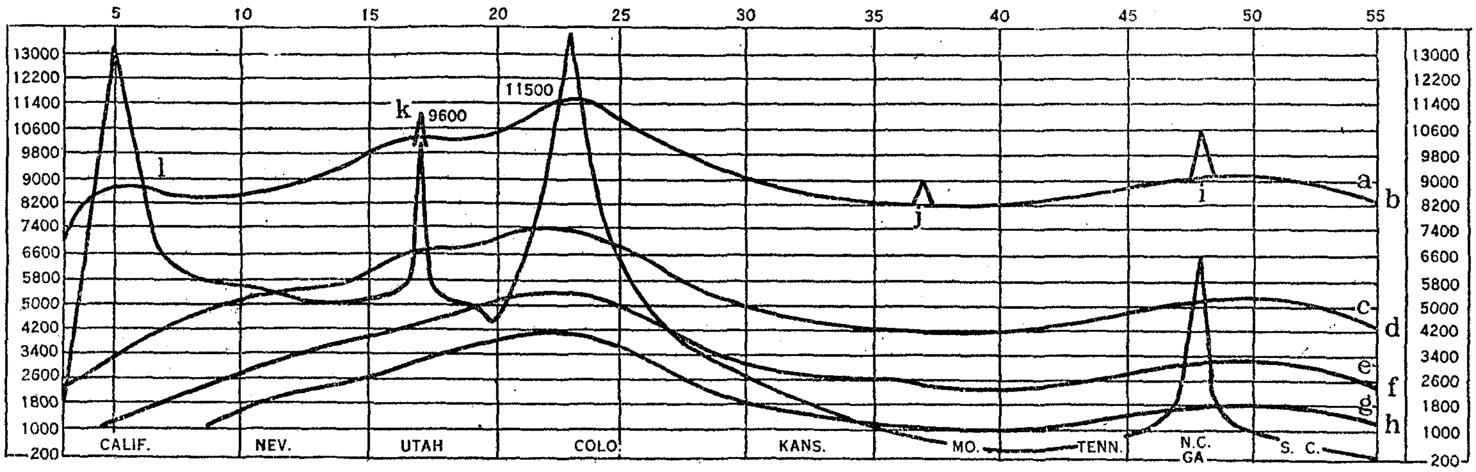


FIG. 5.—Diagram to show the relation of altitude to the positive and negative departures from the various levels along the single isophane of 38 across the United States, as influenced by general topography.

In figure 5 the horizontal lines represent altitudes at intervals of 800 feet from sealevel to 13,000 feet and the vertical lines represent the phenological meridians at intervals of 5 degrees of longitude. Thus the contour profile is enormously exaggerated, yet at the same time it preserves the relative position and altitude of the mountain and valley features. The features represented from east to west are: (1) The Coastal Plain; (2) the Allegheny and Appalachian Mountains and plateaus; (3) the Mississippi River and basin; (4) the Great Plains; (5) the Rocky Mountains and Pikes Peak; (6) the Colorado basin; (7) the Uinta Mountains; (8) the Great Basin; (9) the Southern Cascades; and (10) the Pacific coast. The curved lines *b*, *d*, *f*, and *h* represent the regional and altitude departures from the bioclimatic constants *a*, *c*, *e*, *g*. (*a*) Represents the timber line constant, 9,000; (*b*) the departures from the timber line as influenced by regional and topographic features. Thus: Assume that a mountain in North Carolina (*i*) would have to be 9,000 feet to have a timber line corresponding to that of Mount Washington, then with this as the base, timber line should be—according to the constant (*a*)—at 9,000 feet on Pikes Peak, but instead it is at 11,500 feet, or 2,500 feet higher. This is to be expected because the phenological records on plant and insect phenomena from Colorado Springs to timber line on this mountain show a constant minus or earlier departure of from 24 to 28 days from dates of corresponding events in the east, which would extend the timber line to an equivalent (at 1 day to 100 feet) of about 2,500 feet higher. If there were an isolated peak in the Mississippi Valley 9,000 feet high (*j*), we

fig. 13) and line *d* the corrected line to conform with the influences of topography in causing departures above or below the constant. Levels *e–g* represents the constant range of the optimum altitudes and *f–h* the corrected, *g* the lower altitude constant, and *h* the corrected. Thus it will be seen that, in general, for the whole country the departures from the constant for spring and early summer events are plus for valleys and coasts and minus for plains plateaus, and mountains, and the reverse for late summer and autumn events. This relation of departures from the constant to depressions and elevations of land surface also holds for regions and minor areas down to those of a few acres or even a few rods in extent, so that it may be considered as a law of topographic influence on phenological phenomena, due in part at least to inverted temperatures.

In figure 6 the horizontal lines represent the altitude constants for isophane 43 at intervals of 400 feet and the time constants at intervals of 4 days. The rate of departures from the time constant on north and south slopes will vary with the height of the elevation and degree of slope, also with the character of the valley or plateau at the base. Shreve[16] has found that, for certain mountains in Arizona, the vegetation which is characteristic of certain climatic conditions extends about 1,000 feet lower on the north than on the south slope. Therefore, since 1,000 feet reduced to time is equal to 10 days, there should be a difference of 10 days between the same periodical event on the two slopes. Thus, if we take 3,000 feet as a base and May 1 as the date of a

[16] Carnegie Inst., Wash., Publication No. 217, p. 12, 1915.

periodical event on the south slope, we should find the event occurring on the same date at 2,000 feet on the north slope, or, on the other hand, if we find the altitude limit of a species at 3,000 feet on the south, we should find *its limit on the north slope at 2,000 feet.* Thus, we have in this diagram an illustration of influences which contribute to local departures from the altitude and time constants.

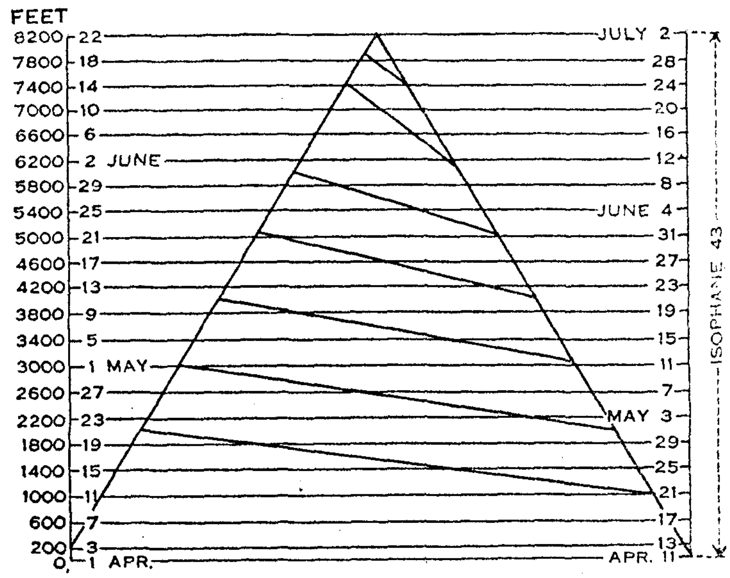


FIG. 6.—Diagram to show the relation of northern and southern slopes to departures from the time constant of a single isophane.

The dates for the southern slope are the constants computed from the 3,000-foot base, while the dates for the northern slope are plus those of the south side for the same levels.

events and altitude limits of organisms, the same date and limit at successively higher levels at the rate of 400 feet to each degree of latitude.

The horizontal lines of the diagram represent levels at intervals of 400 feet on pheno-meridian 50; the oblique lines represent altitudes of equal dates and bioclimatic conditions; the vertical lines, isophanes at intervals of 1 degree; and the profile lines, the altitude of the land surface above the sea on pheno-meridian 50 in the various States, from isophane 32 in Florida to isophane 54 in Canada.

The dates on the lower line represent the sealevel dates on the base line of the diagram and for the oblique lines that intersect the base line above the dates. It will be seen that if (according to this system of expressing the law) the northern limit of tree growth is at sealevel on isophane 60 it should be found at (*a*) 2,400 feet on isophane 54 and at (*b*) 4,000 feet (Mount Washington) on isophane 50. Then for mountains to extend above timber line at *c*, *d*, and *e* their altitudes would have to be (*c*) 6,000, (*d*) 7,600, and (*e*) 8,800 feet. In a like manner, if the northern limit of the culture of spring wheat is at sealevel on isophane 57 the altitude limit should be found at the various isophanes and levels that are intersected by the oblique line starting from 57. If the southern limit of the spruce and the Canadian Zone is at sealevel on isophane 50, it should be found, ± local departures, at the various levels indicated by the oblique line starting from 50, and this is true for the mountains of West Virginia where the lower limit of spruce is at about 2,400 feet between isophane 43 and 44 and at 3,200 on isophane 42. Farther south and west in North Carolina it is between 4,400 on isophane 39 and 4,800 feet on isophane 38.

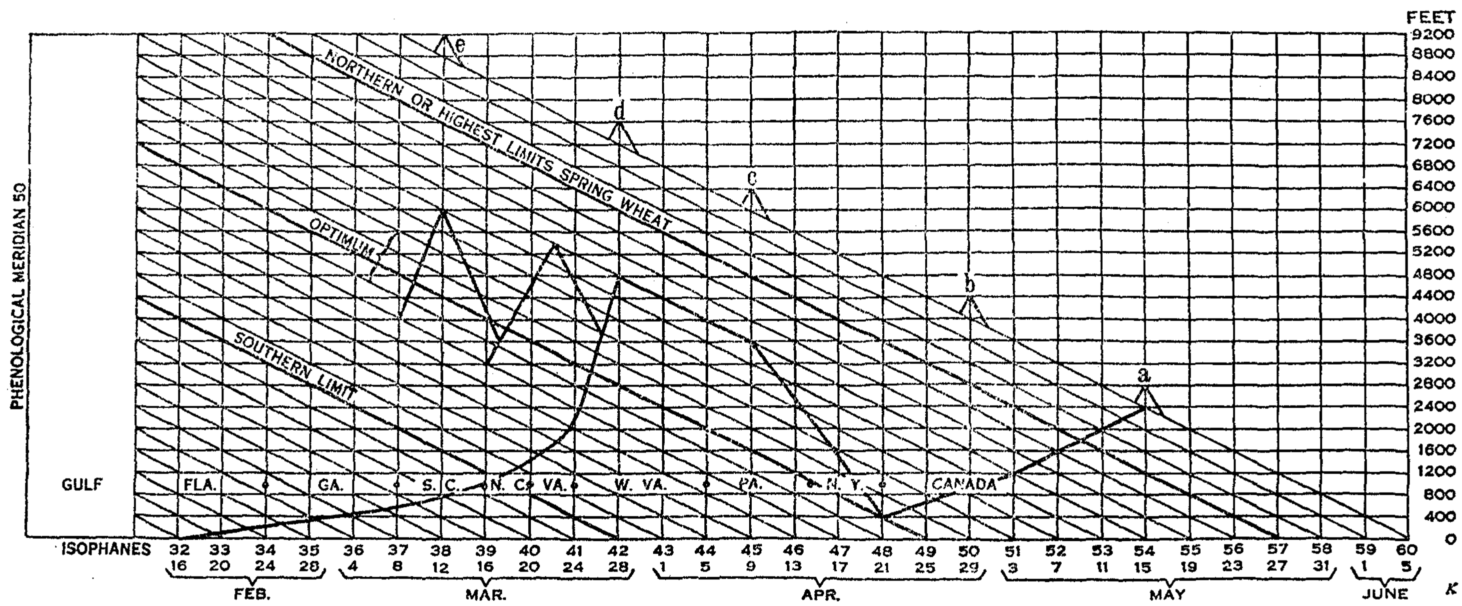


FIG. 7.—Diagram to show the relation of the altitude to the latitude time gradient of 4 days, as applied to a topographic profile along phenological meridian 50.

Figure 7 shows that if we start with a given date of an event at the northern limit of a species at sealevel, and proceed southward, we should find, according to the law of latitude and altitude as related to dates of periodical

In a like manner, if the limit for the optimum of spring wheat culture is at sealevel on isophane 57, with May 3 as the date for seeding, the corresponding altitude limit and the same date should be at the various levels southward as indicated by the oblique isochronal line for May 3 beginning at isophane 57.

The departures from the altitude and date constants should conform to the same law of topographic and slope influences as that mentioned in connection with the discussion (under figs. 5 and 6) of departures from the altitude and time constants for the isophanes.

Evidence of bioclimatic regions.—In a study of the distribution of the average departures for altitudes and for the 1×1 to 5×5 unit quadrangles and the range and limits of the plus and minus departures northwest across the country with the isophanes and northeast with the pheno-meridians, it was plainly evident that the constant departures in one direction over more or less extensive regions furnish a reliable guide to the regions where constant influences prevail to either retard or accelerate periodical responses, especially as applied to the ripening of wheat.

The distribution of the plus and minus departures shows that: (*a*) In the greater part of the New England States and along the coast southward (including New Jersey, southeastern Pennsylvania and Delaware, and northwestern Maryland, eastern North Carolina and South Carolina) there is a region of retarding influences; (*b*) in the Allegheny Plateau and upper coastal plain areas, extending to the coast in Virginia, southeastern Maryland, and southern South Carolina, there is a region of moderate accelerating influence; (*c*) in practically the entire Mississippi Basin from the Allegheny Plateau to the Great Plains and from the Great Lakes to the Gulf of Mexico there is an extensive region of prevailing, and quite marked, retarding influence; (*d*) from about the 1,000-foot level just west of Lake Superior on pheno-meridian 35, the 2,000-foot level in northern South Dakota near pheno-meridian 25, the 2,400- to 3,000-foot level through Nebraska and northwestern Kansas to about the 6,000-foot level in New Mexico, near pheno-meridian 24 and to about pheno-meridian 30 in southwestern Texas, westward across the Great Plains and Rocky Mountains plateaus to about longitude 115°, there is a region of accelerating influence; and that (*e*) westward from about the 115th meridian of longitude, or from between pheno-meridians 10 and 15, there is a region of marked retarding influence which increases rapidly in its intensity toward the ocean as shown by the prevailing and radical plus departures.

Range of departures within the plus and minus regions.—Along the Atlantic coast the boundary of the region of retarding influence is very irregular as indicated by the distribution of the average plus departure and the range in number of days for the 1 × 5 quadrangle units. The greatest departure appears to be along the New England coast with the extremes of about 15 to 20 days in Massachusetts and on Long Island, then decreasing to about 8 days in southern New Jersey, changing to a minus through southern Delaware and through Maryland and Virginia to northeastern North Carolina where a plus of about 7 days is maintained, in southern South Carolina where the minus reaches the coast, then along the southern Georgia coast to Florida there is again a marked plus departure of 17 to 18 days.

In the Appalachian and upper Coastal Plain regions the range in the minus departures is comparatively slight, being from 1 day or less to about 4 days with the average at about 2 days or less.

In the Mississippi Basin, the Great Lakes and Gulf regions the plus departures are fairly constant with a slight average increase from east to west and from north to south, with a range from 1 day or less in the east and north to 30 days in southern Texas, with the average near 6 days for the entire region.

In the Great Lakes region the range is from 1 day or less to 9 days with the average at about 4 days.

In the Great Plains and Rocky Mountains regions the minus departure is fairly regular with the range from 1 day or less to 27 days and the average close to 10 days.

In the Pacific Slope region the range of the plus departure is from 1 day in southern Idaho to 68 days on the Pacific coast near Eureka, Cal., with an average for the whole region of about 25 days. The range for the immediate coastal region from near sea level to 100 miles or more inland is from 19 days in Washington to 68 days in California with the average about 40 days.

The constant character of these departures, all pointing in the same direction within a region, is most significant evidence of the existence and wide range of accelerating and retarding influences which must be associated with peculiar climatic variations from the average of the whole country. Thus, through a study of a single periodical event, we have found a guide to the comparative intensity of the influences in the various regions of the country which contribute to an earlier or later departure of the actual average dates of the event of beginning of wheat harvest, from the theoretical constant.

Investigations have shown that different species and varieties of plants and animals respond in a different degree to the same influences. Therefore, while these preliminary conclusions from the study of wheat harvest apply to but one phase or event of a species and one kind of farm crop within a short period, it includes the average of many varieties and therefore should stand as a good guide for the study of the comparative departures as represented by other species and crops and other lines of farm practice.

Apparent contradictions of the law.—It will be noted from the departure maps for wheat harvest that there is an apparent contradiction of the principle of earlier departures westward and later eastward for an early summer event as applied alone to the eastern, central, or Pacific coast regions. But, taking the country as a whole, there is instead confirmative evidence of this coordinate of the law. When we compare the relation of the departures computed for the quadrangles on isophane 43 (fig. 4), we find—by drawing a line to represent the plus departures south, and minus departures north, of this isophane, at the rate of 4 days to the isophane—that the line for wheat-harvest departures starts nearly 2 degrees north of the isophane along the Atlantic coast, proceeding westward it crosses the isophane to the south in the Alleghenies and attains its southern limit in the central Mississippi Valley at nearly 2 degrees (or +8 days) from the isophane, then ascends rapidly crossing the isophane again to the north on the 100th meridian of longitude and reaches its northern limit at nearly 5 degrees (or −20 days) from the isophane. Then it descends and crosses the isophane again to the south at the 115th meridian, continuing rapidly southward along the Pacific coast to its limit nearly 8 degrees (or +32 days) south of the isophane. Thus, when we come to work out a general average, we find that it is represented by the isophane. Moreover, when we compare the departure line with that of the average sealevel isotherm for the same period of spring development of winter wheat, we find that they closely parallel each other; while throughout there is a decided negative, or earlier, departure from the 38th parallel of latitude in conformity with the law as related to longitude.

Forecasting the dates of events.

The study of harvest dates suggested the application of the system to forecasting dates for harvest, seeding, and other periodical events. It was found that by using the regional and seasonal departures from the theoretical constant we can closely approximate the actual dates of an event such as the beginning of wheat harvest, in any given season. In other words, knowing the number of days departure of a given season from the average, the departures of the date of an event from the theoretical constant for a region and the date of the event for the season at a given base, the corresponding later or earlier date for any other place will be the computed date for the place plus or minus the number of days in the seasonal and regional departures.

Winter wheat seeding dates.—The results of the study of the reported harvest and seeding dates for winter wheat and the recognized need of a guide to the safest dates to avoid damage by the Hessian fly, and best dates to meet the climate requirements for the best yield if the fly is not present, suggested the application of the system to the preparation of map calendars of safest and best dates for seeding. The need for such guides is plainly indicated by the wide range between the first and latest seeding dates reported from each county and section of the country where there are evidently no prevailing natural conditions or good reasons to justify it. In eastern Kansas where, according to Dean,[17] the Hessian fly caused an estimated loss of $32,000,000 in two years (1915–16), it was found from the reports that the average seeding dates up to 1914 had been very much too early to escape the fly. The same was found to be true of other States where the fly has been destructive during recent years, while on the other hand, in Ohio, West Virginia and other States where the reports show that the general seeding was late enough to escape attack by the fall generation of the fly, there has been practically no damage.

It was also shown by the reported dates that a great amount of wheat is sown too late to make a profitable yield on account of winter killing and otherwise weakened conditions of the plants in the spring.

In 1900 the writer suggested, under the head of "The period for sowing fall wheat to secure the best development of the plant and yield of grain,"[18] that—

> As is well known by all observing and experienced farmers wheat can be sown too early and too late to yield the best results. So that for each locality or section of the State there is a proper normal period for sowing wheat.
>
> The normal habit of the wheat plant is governed by the same natural laws as those which govern its enemy, the fly. Therefore the proper normal period for sowing wheat to assure the best crop will vary with the latitude and altitude in the same or similar proportions as that given for the ending of the fall swarm of the fly. Taking from fifteen to twenty days as the normal length of the best period for sowing fall wheat, and assuming that for each locality the commencing of this period is about one week earlier than the normal date for the ending of the fall swarm of the fly, and ending one week or 10 days after this normal date, the map and table not only indicate the proper time to sow wheat at different latitudes and altitudes to avoid the fly, but the best normal wheat sowing period for each locality.

This suggestion has been verified by experiments in Kansas[19] in which experimental sowing by Headlee and Dean during a period of 10 years led the latter to conclude: "In summarizing the time of seeding for the greater part of the wheat belt it may be said that on an average seedbed when Hessian fly is not present in damaging numbers the maximum yield of wheat will be obtained in an average season by seeding a little earlier than the fly-free date."

In the experiments of nine years to determine the relation of dates of seeding to injury from the Hessian fly conducted at Columbus, Ohio, it was shown[20] that the average of the dates which gave the best yields was September 29 or four days later than the average safe date (Sept. 25) as given by Webster.

The results of experiments to determine the relation of date of seeding to yield of grain conducted for nine years at Wooster, Ohio, show[20] that the average date for best yield was September 19 or one day earlier than the safe date, (Sept. 20) for this locality as given by Webster.

In a later bulletin[22] it is shown that experimental sowing at Wooster, Ohio, during a period of 14 years, 1902 to 1915, gave the largest average yield from seeding on September 21–22, or an average of 1½ days later than the determined fly-free or safe date (Sept. 20). This record

[17] Journ. Econ. Entom., February 1917, p. 159.

[18] Bulletin 67, W. Va. Univ., Agric. Exp. Sta., pp. 246-247.
[19] Journ. Econ. Entom., No. 1, 1917, p. 149.
[20] Bull. 136, Ohio Exp. Station, 1902, p. 13. Table II.
[21] Bul. 231, Ohio Experiment Station, 1911, p. 6. Table IV.
[22] *Bul. 298, Ibid. 1916, p. 460. Table IX.*

is of especial importance as confirmatory evidence of the close relation between the best and safest dates because during this period there was evidently no appreciable damage from the fly to affect the yield.

This knowledge of the relation of the time of seeding winter wheat to avoid injury from the fall attack of the Hessian fly and otherwise to secure a maximum yield shows the importance of some system of simple guides for wheat growers, which will enable them to select the proper time or period for any locality within the United States where the conditions are favorable for the profitable growth of winter wheat.

Proposition to make wheat-seeding map-calendar for all the States.

The greatly reduced damage by the Hessian fly following the publication of a wheat-seeding map-calendar for West Virginia[23] in 1900 together with the urgent need of increasing the wheat crop of 1918 led the writer early in July, 1917, to propose that he should prepare wheat-seeding map-calendars for the States in which winter wheat is grown and that their publication and distribution be such that they would reach the farmers in time to be utilized in the fall of 1917.

This proposition was made under authority from the Chief of the Bureau of Entomology in a conference with Dr. R. A. Pearson, who had recently been appointed Assistant Secretary to take charge of the activities of the department toward increasing the food supply. Following the conference and the suggestion by Dr. Pearson, the writer conferred with the Chief of the Office of Farm Management and Mr. C. B. Smith of the States Relations Service, in charge of the Northern Division of the Extension Service. This conference was held in the office of the Chief of the Office of Farm Management on July 6, at which the writer presented his proposition, which was adopted.

By the last of July the writer had completed his part of the work in the preparation of maps and calendars for the States in which winter wheat is grown as a more or less important crop, and the computed dates of the calendars had been corrected with the aid of Dr. C. F. Brooks, then connected with the Office of Farm Management, to meet the requirements of regional influences tending to cause earlier or later dates.

Owing to limited time, posters were prepared for only New York, Pennsylvania, Illinois, Indiana, Nebraska, New Jersey, West Virginia, Oklahoma, Virginia, North Carolina, and Tennessee.

The poster for North Carolina is reproduced here (fig. 8) to serve as an example and record of the form and the information conveyed.

Wheat-seeding map-calendar for West Virginia, with explanations and instructions.

The original explanations and instructions that had been prepared to accompany the map-calendar posters were changed and condensed to meet the editorial requirements of a poster. Therefore, it seems desirable to give more detailed explanation and instructions in connection with a slightly revised map-calendar for West Virginia to serve as an example of this method of making the information available to wheat growers.

The dates given in the calendar (fig. 9) are safest because, if the Hessian fly is present, wheat sown earlier than the first given date will be in danger of attack in the fall, and because neighboring fields sown late enough to escape in the fall will be in danger of attack in the spring from the flies that emerge from the early sown wheat.

The given dates represent (other things being equal) the best average time to sow wheat to secure a maximum yield, because observations and experiments have shown that the safest date to sow wheat to escape the fly when it is present is, in general, the best date for the development of the plant if the fly is not present. The best period will be within 10 days after the given dates.

The oblique latitudinal lines on the map are drawn to represent one-fourth of a degree of latitude and to express the average variation due (according to the bioclimatic law) to latitude and longitude. Thus they represent theoretical lines of equal bioclimatic conditions (isophanes) at the same level. For example, if all the local and regional conditions were equal, winter wheat should be ready to harvest on the same date at the same average altitude anywhere along one of these lines.

The oblique longitudinal lines (phenological meridians) are drawn at right angles to the isophanes to represent 1 degree of longitude and with the isophanes to form $\frac{1}{4} \times 1$ degree quadrangles.

The isophanes and meridians are designated by a set of standard numbers in order that they may serve the same purpose as the true parallels of latitude and meridians of longitude in defining the geographical positions of a place or quadrangle.

The $\frac{1}{4} \times 1$ degree quadrangles on this map have no relation to the calendar, because the given dates are for the given altitudes anywhere between two isophanal lines for which the dates are given. However, when the average altitude of the area embraced in a quadrangle is the same as, or near to, a given altitude in the calendar the given date and period for that altitude will serve for the entire quadrangle.

It should be remembered that (1) the given altitude is for a general average elevation above the sea and, therefore, is for comparison with the average altitude of a quadrangle, county, district, or local area, and that the dates are for the average season. Therefore neither the given altitudes or dates are for a specific place or farm or a given season. If the altitude range for a locality or larger area is between 1,000 feet and 1,400 feet, the average would be 1,200 feet, in which case the seeding date would be two days earlier for 1,200 feet than the date given for 1,000 feet and two days later than that given for 1,400 feet.

(2) Owing to the variations in seasons and to variations due to local influences of valleys and hills and to local weather and other conditions, there may be a considerable local departure in the safest and best date from that given in the calendar. Therefore, in the use of the calendar each wheat grower must be guided to a certain extent by his experience and that of his neighbors as to an interpretation of the influences of the season, weather, and local conditions.

(3) There are other precautions and requirements besides the dates and periods of sowing to avoid damage from the fall and spring attack of the fly and also certain requirements of cultural methods which are essential to a maximum yield. Therefore, when the wheat grower is in doubt as to the minor questions and details about the insect or the practice of wheat culture he should write to the proper State or Federal institution for information.

To find the dates for any locality in the State where wheat is or can be grown.—(1) Locate the general position of the required area or place on the map and determine the average altitude of the general area.

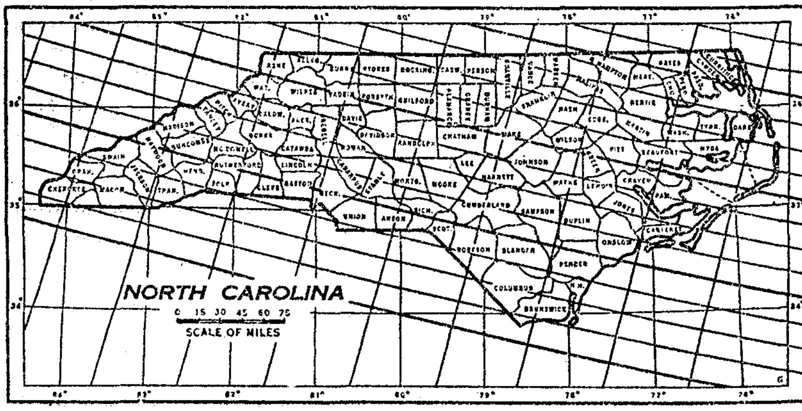
(2) Follow the nearest isophanal line, south of the location, to the calendar, and find on the corresponding line the date in the column which is headed by the altitude nearest to the average of that of the local area.

[23] Bulletin 67, W. Va. Experiment Station.

BEST TIME TO SOW WINTER WHEAT

GIVE THE HESSIAN FLY NO CHANCE

YOUR SAFEST SOWING DATES IN A NORMAL SEASON



ALTITUDE IN FEET ABOVE SEA LEVEL										
200	400	800	1200	1600	2000	2400	2800	3200	3600	4000
OCT. OCT. 15 TO 25										
16 TO 26										
17 TO 27	OCT. OCT. 15 TO 25									
18 TO 28	16 TO 26	OCT. OCT. 12 TO 22								
19 TO 29	17 TO 27	13 TO 23	OCT. OCT. 9 TO 19	OCT. OCT. 5 TO 15	OCT. OCT. 1 TO 11	SEP. OCT. 27 TO 7	SEP. OCT. 23 TO 3	SEP. SEP. 19 TO 29	SEP. SEP. 15 TO 25	
20 TO 30	18 TO 28	14 TO 24	10 TO 20	6 TO 16	2 TO 12	28 TO 8	24 TO 4	20 TO 30	16 TO 26	SEP. SEP. 12 TO 22
21 TO 31	19 TO 29	15 TO 25	11 TO 21	7 TO 17	3 TO 13	29 TO 9	25 TO 5	OCT. 21 TO 1	17 TO 27	13 TO 23
NOV. 22 TO 1	20 TO 30	16 TO 26	12 TO 22	8 TO 18	4 TO 14	30 TO 10	26 TO 6	22 TO 2	18 TO 28	14 TO 24
23 TO 2	21 TO 31	17 TO 27	13 TO 23	9 TO 19	5 TO 15	OCT. 1 TO 11	27 TO 7	23 TO 3	19 TO 29	15 TO 25
24 TO 3	NOV. 22 TO 1	18 TO 28	14 TO 24	10 TO 20	6 TO 16	2 TO 12	28 TO 8	24 TO 4	20 TO 30	16 TO 26
25 TO 4	23 TO 2	19 TO 29	15 TO 25	11 TO 21	7 TO 17	3 TO 13	29 TO 9	25 TO 5	OCT. 21 TO 1	17 TO 27
26 TO 5	24 TO 3		16 TO 26	12 TO 22	8 TO 18	4 TO 14	30 TO 10	26 TO 6	22 TO 2	18 TO 28
27 TO 6			17 TO 27	13 TO 23	9 TO 19	5 TO 15	OCT. 1 TO 11	27 TO 7	23 TO 3	19 TO 29
28 TO 7			18 TO 28	14 TO 24	10 TO 20	6 TO 16	2 TO 12	28 TO 8	24 TO 4	20 TO 30

Comparison of usual dates, reported by farmers in 1914, with the corresponding Calendar dates:

	Reported	Calendar
Northwest	September 25	September 24 to October 4
East Central	November 2	October 20 to 30

Difference: In East, Reported, a week later than Calendar dates.

SOW AFTER FIRST DATES TO AVOID FLY

The Hessian fly is not troubling you much now, because most farmers in North Carolina have been sowing wheat after fly-free dates. The Hessian fly menaces those who sow too early.

Destroy all volunteer grain by plowing, disking, or otherwise.

Cooperate with your neighbors to sow just after the fly-free dates. One early-sown field may infest all the others next spring.

HOW TO FIND YOUR BEST SOWING DATES

1. Find your county, then find the position of your farm in the county.
2. Follow the nearest line below your location to the calendar on the right of the map
3. On this line find your dates in the column which is headed by the altitude nearest the average elevation of your general locality.

IN A NORMAL SEASON, you should not plant before the earliest date, and, if possible, you should have the seed in the ground by the latest date.

Use your experience and judgment in interpreting these dates to apply to your own conditions this season.

SOW BEFORE LAST DATES TO AVOID WINTER KILLING

HAVE YOUR SEED BED PREPARED IN THE BEST POSSIBLE MANNER—finely pulverized and firmly compacted. Early pulverization and fallowing will conserve moisture and soluble plant food so that the wheat, even though sown late, will grow quickly and strongly.

When in doubt, write to the State or Federal entomologist for information and advice on the fly; or to the County, State, or Federal authorities on agricultural practice for information and advice in general.

Your Entomologist is FRANKLIN SHERMAN, Raleigh, N. C.
State Extension Director: B. W. KILGORE, Raleigh, N. C.

U. S. DEPARTMENT OF AGRICULTURE

SEPTEMBER, 1917

FIG. 8—Wheat-seeding map-calendar poster for North Carolina.

The given date is for the earliest of the safe dates. The end of the best period is about 10 days later, although wheat may be, under favorable conditions, sown considerably later with good results or a few days earlier than the given date if the fly is not present.

(3) This map calendar is intended simply as a guide to wheat growers in the selection of the time which on the average is likely to yield the best results. It is not by any means to stand as a fixed rule for specific seasons, localities, or altitudes. Its chief purpose for the present is to serve as a guide to further investigations by the State entomologists and agriculturists relating to the influence of local conditions, variation in seasons and the weather, and the date of the general emergence and disappearance of the Hessian fly; also as to the time of seeding which will yield the best local results toward the attainment of a maximum crop.

Natural guides to the time to sow winter wheat.

Since the time of emergence and disappearance of the Hessian fly in the autumn and the best time to sow wheat for the development of the plant is governed by the same law as that which governs the periodical autumn events of other life activities, we should find in the autumn events of some wild or cultivated plant or group of plants a reliable natural guide to the selection of the best date and period to do the work.

Special attention was given to a study of this problem during the autumn of 1917 in connection with the writer's practical application of the principle in sowing wheat on his own farm. It was found that the time when the tall late goldenrod (*Solidago altissima*) was in full bloom and the flowers were nearly all fallen from the ornamental clematis vine (*Clematis paniculata*) was simultaneous with the calendar date for beginning to sow wheat in that locality, and that the time the flowers on the goldenrod begin to fade was coincident with the date 10 days later or the end of the best period. Therefore, it is probable that one or both of these plants will serve as a good guide for any other locality or farm within the range of winter wheat culture where the species of goldenrod grows naturally or where it and the clematis can be successfully transplanted. If transplanted, the plants should be secured from the same or the nearest possible locality.

There are doubtless other wild and cultivated plants growing, or that can be grown, in every locality which would furnish in their periodical flowering or fruiting events equally as good, or perhaps better, guides to the exact time to sow wheat to conform to the requirements of the law and the departure influences of the regional and immediate local conditions of a farm or field.

With such natural guides growing on the farm the calendar dates would serve as guides to the general average time and the guide plant would serve to indicate the more exact time for any season or any local condition which exerted a common influence on the crop plant, the insect enemy, and the guide plant.

Therefore, every wheat grower in the State should note the flowering or other conspicuous events in the wild and cultivated plants on his farm at the time of the calendar dates for his locality or at the earlier or later date which, on account of the season or local conditions, seems to be more correct, and then note the result in the comparative development, maturing, and yield of the crop from seeding at different dates coincident with different guide events. (See pp. 35, fig. for further discussion of the relation of periodical events in plants to corresponding events in farm crops and practice.)

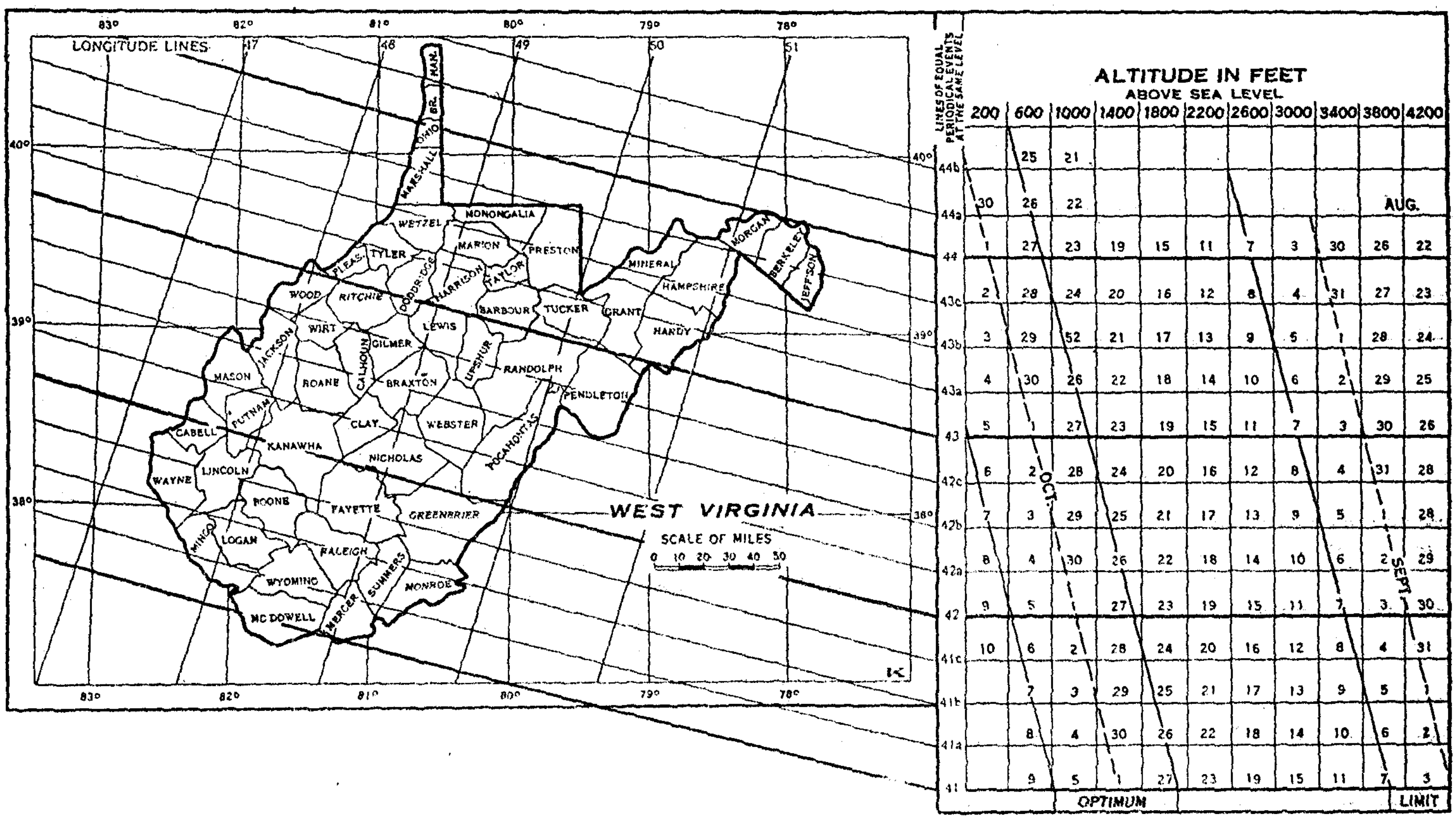


FIG. 9.—Wheat seeding map-calendar of West Virginia, to show the map-calendar method of furnishing guides for wheat growers to the safest and best time to seed for any latitude or altitude.

Wheat-seeding map-calendar for the United States.

The fact that so few of the calendar maps that had been prepared for all of the States were issued seems to render it desirable to present in this connection a summary of the results in a wheat seeding map calendar for the United States (fig. 10).

In this calendar the computed constant dates are given for 1-degree isophanes instead of the ¼-degree isophanes of the State maps. These dates apply to the first ¼-degree isophane above the isophanal lines for which the date is given; therefore, to be more exact, one day is to be subtracted from the calendar date for localities in each additional ½-degree to the next 1-degree isophane north.

The dates are to be further corrected for regional influences by adding or subtracting the + or − number of days given for States in figure 12 and the 5×5 quadrangle in figure 11. In addition to these corrections, as in those for the map calendar for West Virginia, the wheat grower must be guided by experience in adjusting the dates to meet the requirements of the season and local accelerating or retarding influences.

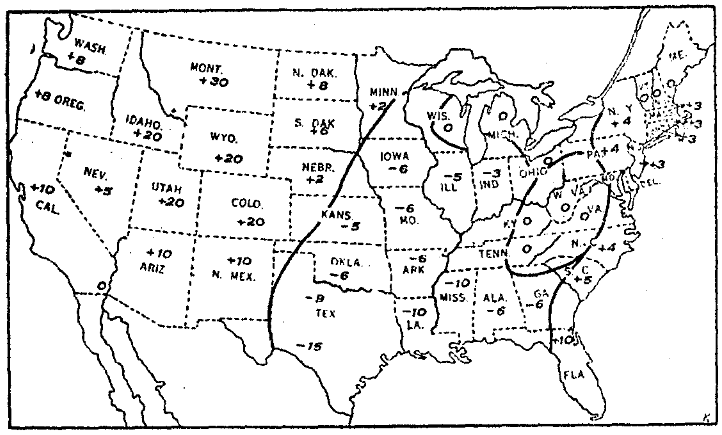


FIG. 12.—Map of the United States with estimated average departures by States, for fall and late summer events.

It must be considered that this map calendar is for general average seasons, average altitudes and general conditions and that it is presented here merely as an example of the method and to serve as a guide to further investigations, observations, experiments, etc., relating to the best time to sow winter wheat with the hope that such investigations will ultimately lead to the development of more accurate calendars as applied to regional and local conditions.

Corrections for regional and local departures.—While the map calendar of wheat seeding dates for the United States necessarily gives only the theoretical constants, these constants can be modified to more nearly coincide with the actual average for the various regions and States by adding or subtracting the estimated departures as given on the maps forming figures 11 and 12. In making such corrections, however, it is much better to employ the map calendar for the United States corrected for the average departures for the States, as a basis for constructing separate or adjustable calendars for the State under consideration.

To facilitate the selection of an arbitrary base for a State, until a determined one can be established, Table 2, of corrected dates and altitude averages, is given from which preliminary State calendars of winter wheat seeding dates can be constructed.

From this table calendars of corrected dates for an isophanal map of a State may be constructed (see p. 31), which will serve as a good working basis for investigations to determine facts on which to make further corrections.

TABLE 2.—*Estimated corrected dates and altitudes for the computing base employed in constructing preliminary State calendars of winter wheat.*

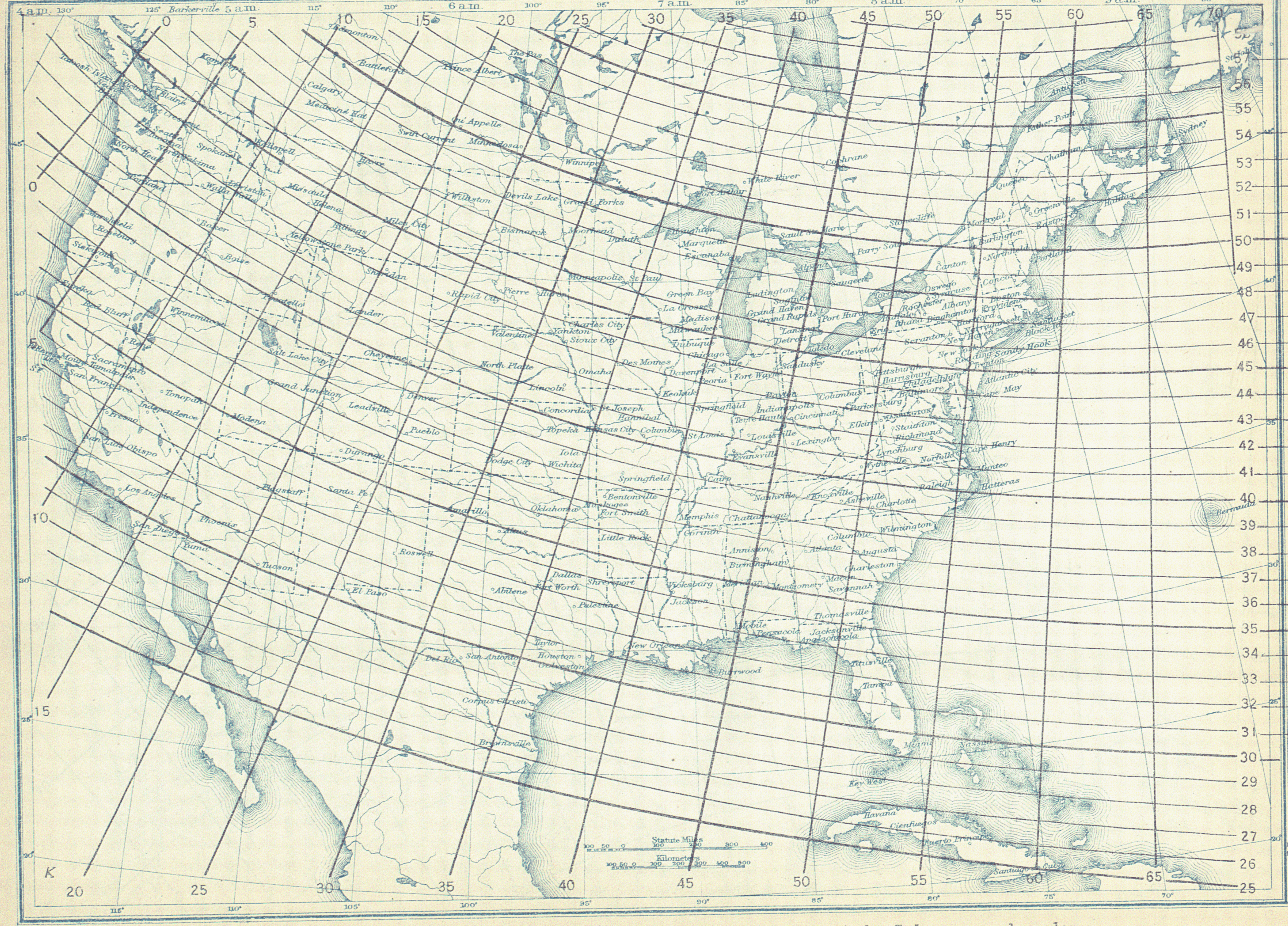
Isophanes.	States, altitudes, and dates.
50	*Maine*, altitude 200 feet, Sept. 6.
49	*Vermont*, altitude 200 feet, Sept. 10; *New Hampshire*, 200 feet, Sept. 10.
48	*New York*, altitude 600 feet, Sept. 14; *Massachusetts*, 200 feet, Sept. 14.
47	*Connecticut*, altitude 600 feet, Sept. 17; *Michigan*, 600 feet, Sept. 14; *Minnesota*, 1,400 feet, Sept. 6; *Rhode Island*, 200 feet, Sept. 21; *Wisconsin* 1,000 feet, Sept. 10; *North Dakota*, 1,800 feet, Sept. 10.
46	*Pennsylvania*, altitude 1,400 feet, Sept. 14.
45	*Montana*, altitude 4,200 feet, Sept. 16; *New Jersey*, 600 feet, Sept. 25.
44	*Delaware*, altitude 200 feet, Oct. 3; *Ohio*, 1,000 feet, Sept. 22; *South Dakota*, 2,200 feet, Sept. 16.
43	*Idaho*, altitude, 3,400 feet, Sept. 22; *Indiana*, 600 feet, Sept. 27; *Iowa*, 1,000 feet, Sept. 20; *Maryland*, 1,000 feet, Sept. 29; *Washington*, 1,400 feet, Sept. 30; *West Virginia*, 1,400 feet, Sept. 22.
42	*Illinois*, altitude 600 feet, Sept. 29; *Virginia*, 1,400 feet, Sept. 26; *Wyoming*, 3,400 feet, Sept. 26.
41	*Kentucky*, altitude 600 feet, Oct. 8; *Nebraska*, 1,800 feet, Sept. 28.
40	*Missouri*, altitude 600 feet, Oct. 6; *North Carolina*, 1,400 feet, Oct. 8; *Oregon*, 2,200 feet, Oct. 6.
39	*Kansas*, altitude 2,200 feet, Oct. 5; *Tennessee*, 1,400 feet, Oct. 8.
38	*Colorado*, altitude 6,200 feet, Sept. 14; *South Carolina*, 600 feet, Oct. 25; *Utah*, 5,400 feet, Sept. 22.
37	*Arkansas*, altitude 1,000 feet, Oct. 14; *Georgia*, 1,000 feet, Oct. 14.
36	*Alabama*, altitude 1,000 feet, Oct. 18; *Nevada*, 5,400 feet, Sept. 15; *Oklahoma*, 2,200 feet, Oct. 6.
35	*Mississippi*, altitude 600 feet, Nov. 11.
34	*California*, altitude 2,200 feet, Oct. 30; *New Mexico*, 5,000 feet Oct. 2; *Texas*, 2,200 feet, Oct. 5.
33	*Arizona*, altitude 4,600 feet, Oct. 10; *Louisiana*, 200 feet, Nov. 28.

The average altitudes and dates given in Table 2 are for approximately the center of a State, therefore they involve variations north, south, east and west from the central base. The character of this variation will be indicated by the average departure for the adjoining States. In Nebraska, for example, the average departure is estimated at +2 days, but Iowa on the east has −6 days, Kansas on the south −5 days, Colorado +20 days, Wyoming +20 and South Dakota +6 days. This shows that toward the borders of the State the dates are to be corrected by a greater or less number of days than the average, especially when more accuracy is desired than is obtained in the results based on a State average. This modification from the average will have to be worked out from the average county or quadrangle dates of the beginning of wheat harvest and from special phenological records, etc., in order to arrive at fairly reliable conclusions as to the average departures for the various local areas of a State.

Altitude limits of winter wheat culture.

The theoretical limits of profitable culture of winter wheat may be approximately determined for the United States, or a State, by means of the computing table of altitude limits (Table 3).

As an example of its application we will take 3,000 feet on isophane 43 in West Virginia as the altitude limit base. Other things being equal, the corresponding limits will be −400 feet north and +400 feet south for each isophane. This would give us the limit at sea level on isophane 50b in Maine and at 7,400 feet on isophane 32 in Arizona. But, as has been shown by the variation from the constant dates for harvest and seeding due to regional influences as represented in plus and minus departures, we



ALTITUDE IN FEET ABOVE SEA LEVEL

200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600	5000	5400	5800	6200	6600	7000	7400	7800	8200	8600	9000	9400
25	21	17	13	9	5	1	28	24															
29	25	21	17	13	9	5	1	28	24														
2	29	25	21	17	13	9	5	1	28	24													
6	2	29	25	21	17	13	9	5	1	28	24												
10	6	2	29	25	21	17	13	9	5	1	28	24											
14	10	6	2	29	25	21	17	13	9	5	1	28	24										
18	14	10	6	2	29	25	21	17	13	9	5	1	28	24									
22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24								
26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24							
30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24						
4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24					
8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24				
12	8	4	30	26	22	18	14	10		2	29	25	21	17	13	9	5	1	28	24			
16	12	8	4	30	26	22	18	14	10		2	29	25	21	17	13	9	5	1	28	24		
20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24	
24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28	24
28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1	28
1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5	1
5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9	5
9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13	9
	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17	13
17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21	17
21	17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25	21
25	22	17	13	9	5	1	28	24	20	16	12	8	4	30	26	22	18	14	10	6	2	29	25

AUGUST — JULY — SEPTEMBER — HIGHEST LIMIT — OPTIMUM — OCTOBER — NOVEMBER — LOWEST LIMIT

Fig. 10.—Winter wheat-seeding map calendar of the United States in 1- by 5-degree quadrangles.

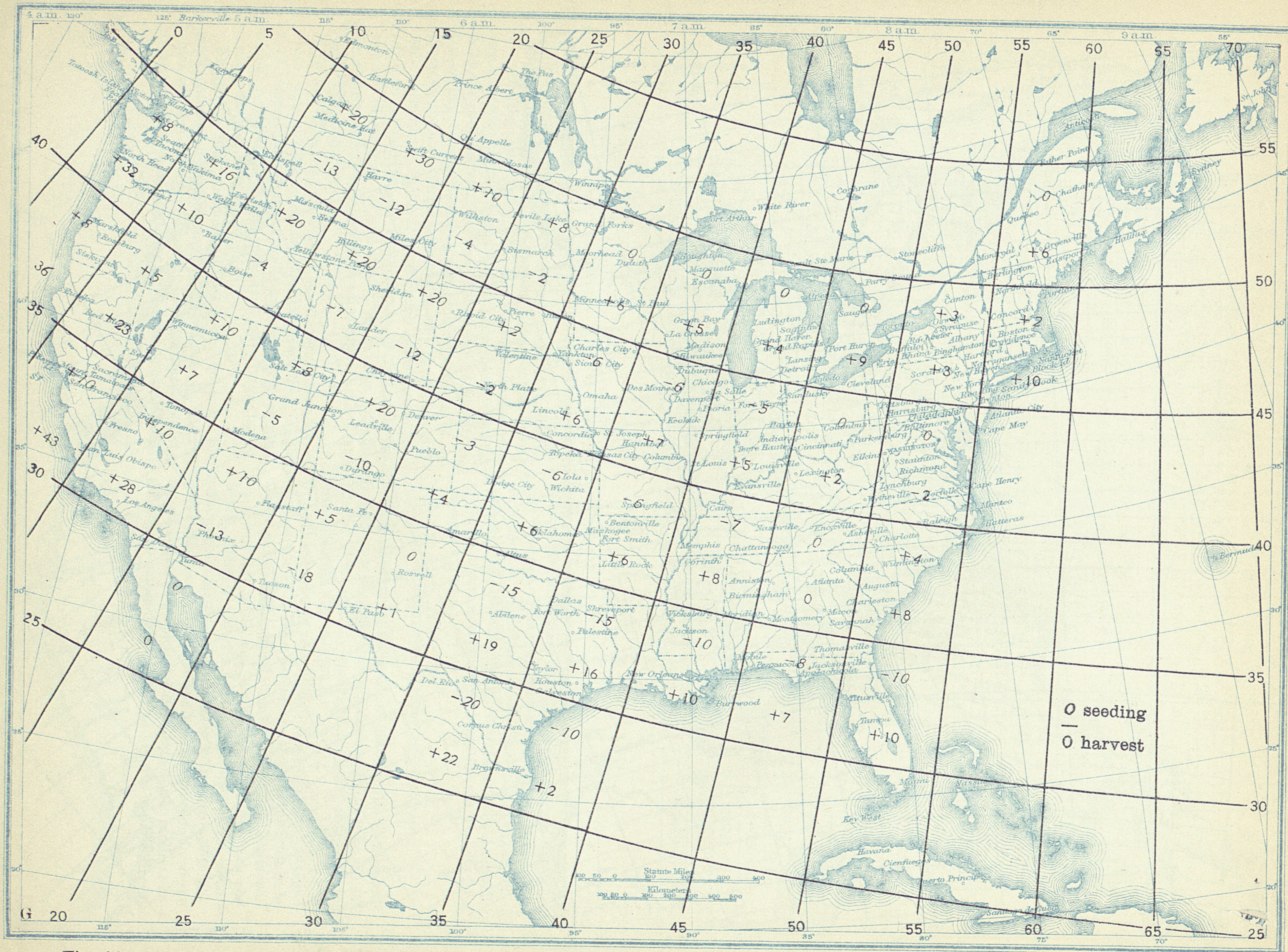


Fig. 11.—Isophanal map of the United States, in 5- by 5-degree quadrangles, to show method of indicating quadrangle and regional departures of estimated seeding and reported harvesting dates, from computed calendar dates.

should and do find a variation in altitude limits from the computed altitude constant in direct proportion to the variation from the time constant.

These variations, as represented in plus and minus departures in hundreds of feet, have been estimated from the reported highest altitudes for winter wheat in each State; also from the reported dates of seeding and the relation of the departures in harvesting and seeding dates to the regions and altitudes. Thus we have in this table and the departures from the altitude constants a fairly good guide to the regional influences in raising or lowering the altitude limits of winter wheat culture. (See diagram, fig. 5.)

While these limits are only given as approximate averages it is believed that, with the exception of the Pacific slope with its complexity of climatic condition as compared with the other bioclimatic regions, they will be found, with the required plus and minus corrections, much nearer to the actual than can be predicted by any other method that has been available up to this time.

It is realized that winter wheat can be grown, with more or less success, at higher altitudes and farther north than the given limits, but as compared with spring wheat, which is successfully grown at and above these limits, it is evident that the corrected altituaes will represent a fairly reliable average.

TABLE 3.—*Computing table for altitude limits of winter wheat culture with estimated departures for each State.*

Isophane.	Altitudinal constant.	Departures for regional influences.
1	2	3
	Feet.	
50b	0	....
50	200	*Maine*, 0.
59	600	*Vermont*, 0; *New Hampshire*, 0.
48	1,000	*Massachusetts*, 0; *New York*, +400.
47	1,400	*Michigan*, 0; *Wisconsin*, 0; *Minnesota*, +200; *North Dakota*, +800.
46	1,800	*Pennsylvania*, +400.
45	2,200	*Montana*, +3,000.
44	2,600	*South Dakota*, +1,000.
43	3,000	*West Virginia*, 0; *Idaho*, +2,000; *Washington*, 0.
42	3,400	*Virginia*, 0; *Wyoming*, +2,000.
41	3,800	*Nebraska*, +800.
40	4,200	*North Carolina*, +300; *Oregon*, 0.
39	4,600	*Kansas*, −500.
38	5,000	*Colorado*, +2,000; *Utah*, +800.
37	5,400	....
36	5,800	*Nevada*, +800.
35	6,200	....
34	6,600	....
33	7,000	*New Mexico*, +600; *California*, 0.
32	7,400	*Arizona*, +600.
31	7,800	....
30	8,200	....
29	8,600	....
28	9,000	....
27	9,400	....

This table is given here merely as a working example for practice in the application of the method in connection with a study of the problem.

The theoretical altitude constant is for the given isophane and not for an average of a State. The given departures are, however, based on estimated average altitudes for each of the given States and consequently will vary east and west from the center. For example, in North Dakota, South Dakota, Nebraska, and Kansas, the plus departure or higher altitude increases westward and changes to a minus departure eastward. The fact that in these States the altitude limits are toward the western borders, requires that the positive correction of the altitude limits be increased westward.

The application of this table to the determination of comparative altitude limits in West Virginia will serve as an example for its application to other States. Here we find that the higher altitudes of the State come between isophanes 44b and 41, with isophane 43 and 3,000 feet as the limit base. This gives the indicated altitude limit at from about 2,700 feet at isophane 43c in the northeastern corner of Preston County to 3,800 feet on isophane 41 in McDowell County in the southern part of the State.

For a more detailed computation of altitude limits for a State, a separate table should be constructed with a corrected base as, for example, Idaho with isophane 43, 3,000 + 2,000 = 5,000 feet as the limit base, then compute and estimate from this and recorded data, the altitude limits for the other isophanes. The reported average altitudes for Idaho range from 2,400 in Bonner County on isophane 45a to 5,000 feet in Lemhi County on isophane 42a to 6,000 in Bear Lake County on isophane 40 and Bonneville County on isophane 41 and 2,300 feet in Canyon County on isophane 40b.

APPLICATION OF THE COMPUTING TABLE AND CALENDAR SYSTEM TO THE COMPUTATION OF DATES, PERIODS, LIMITS, AND OPTIMUM IN WHEAT CULTURE.

Computing table for seeding and harvest dates and periods of development of winter wheat.[24]

A study of the averages of the reported seeding and harvest dates and periods for winter wheat, as given in "Seedtime and Harvest,"[25] and their relation to the isophanes on map 8 resulted in the construction of a computing table (table of fig. 13) to serve as a guide to the computed constant dates for seeding and harvest and the periods of development, for any isophane and altitude, and also to indicate the northern and southern isophanal limits, the altitudinal limits and a theoretical optimum range of altitude for each isophane.

This table is based on the theoretical constant computed from the Wooster base, therefore the dates, altitudes and periods are subject to the same rates of correction for regional and local influences as in the maps figures 11, 12, and 14.

It will be noted that the variation in dates for seeding and harvest are at the constant rate of four days to the isophane and that the periods increase northward and decrease southward from the base at the constant rate of eight days to the isophane.

[24] For explanations of computing tables, their construction and use, see pp. 29 to 31.
[25] Covert, J. R. Bulletin 85, Bureau of Statistics, 1912.

It will also be noted that the theoretical northern, southern, and altitude limits of the profitable culture of winter wheat are indicated on this table by oblique isochronal lines. Evidences gathered from the reported data on winter wheat indicate that, where the isophane or altitude gives the computed date constants of September 6 for seeding, July 16 for harvest and a period of 313 days, it represents the northern and highest limit. In a like manner, where the isophane and altitude gives a constant of November 5 for seeding, April 17 for harvest, and a period of 193 days, it represents the southern or lower limit. Between these two limits there should be an optimum where, other things being equal, the wheat plant should thrive best and its culture be the most profitable.

Assuming that the optimum conditions for winter wheat prevail in the States where the greatest amount of winter wheat is grown with the least injury from adverse climatic conditions, we find that it is represented by a zone through Kansas, southeastern Nebraska, southern Iowa, northern Missouri, central Illinois and Indiana, and southern Ohio. Taking this as the base, other areas like eastern Kentucky and Tennessee, western West Virginia, a small part of western Virginia, a

ISO-PHANE	SEED-ING DATES	HAR-VEST DATES	PERI-ODS	FEET ABOVE SEA LEVEL																							
				200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600	5000	5400	5800	6200	6600	7000	7400	7800	8200	8600	9000	9400
50	S. 6	JL. 16	313	313																							
49	10	12	305		313																						
48	14	8	297			313																					
47	18	4	289				313																				
46	22	JE. 30	281					313																			
45	26	26	273						313																		
44	S. 30	22	265							313																	
	OCT. 2	20	261																								
43	4	18	257								313																
42	8	14	249									313															
41	12	10	241										313														
40	16	6	233											313													
39	20	JE. 2	225												313												
38	24	MY 29	217													313											
37	O. 28	25	209														313										
36	N. 1	21	201															313									
35	5	17	193	193															313								
34	9	13	185		193															313							
33	13	9	177			193															313						
32	17	5	169				193															313					
31	21	MY 1	161					193															313				
30	25	AP. 27	153						193															313			
29	N. 29	23	145							193															313		
28	D. 3	19	137								193															313	
27	7	15	129									193															313

NORTHERN AND HIGHEST ALTITUDE LIMIT SEEDING, SEP. 6; HARVEST, JULY 16; PERIOD, 313 DAYS.

SOUTHERN LIMIT

FIG. 13.—Table for computing seeding and harvest dates, periods of development, limits and optimum for winter wheat in the United States (illustrating the method).

verse climatic conditions, we find that it is represented by a zone through Kansas, southeastern Nebraska, southern Iowa, northern Missouri, central Illinois and Indiana, and southern Ohio. Taking this as the base, other areas like eastern Kentucky and Tennessee, western West Virginia, a small part of western Virginia, a considerable area northeastward through Virginia and extending across eastern Maryland, Delaware, and southern New Jersey should be included.

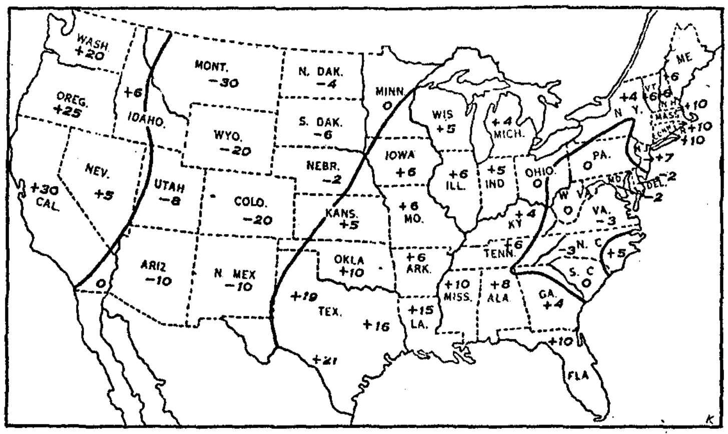


FIG. 14.—Map of the United States with estimated average departures, from calendar dates, by States for spring and early summer events.

Taking this zone as a base from which to compute a theoretical constant, we find, as shown by the isochronal lines transferred from the table to the map (fig. 15), that a theoretical range of the optimum can be computed from the table by the isophanal system and shown on the map by the isochronal system.

It must be remembered, however, that the above discussion is based on the computed constants which are subject to modification to meet the requirements of regional and local departures (see figs. 12 and 14).

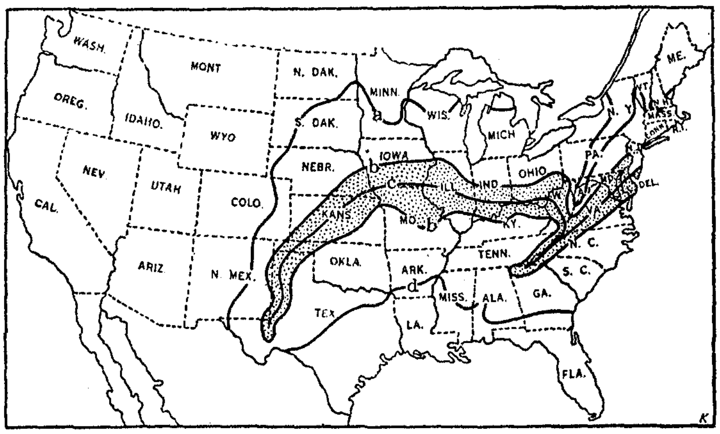


FIG. 15.—Map of the United States to show the approximate range of the culture of winter wheat in the States east of the Rocky Mountains. a=northern limit; b,b,=optimum range; c=optimum mean; d=southern limit.

It will be noted that the 600- to 1,000-foot levels on isophanes 42 and 41, embrace an extensive area through Virginia, West Virginia, Ohio, Indiana, Illinois, Iowa, Kentucky, Missouri, and Nebraska, which in fact represents the center of the winter wheat region of the country, but this does not imply that adverse soil and local climatic conditions could not remove certain areas from the optimum.

Applying the principle of computing the limits of winter-wheat culture and the optimum (fig. 13) to West Virginia we find that the altitude limit on isophane 43 is at the 3,000-foot level and that the theoretical optimum comes below 600 feet on isophane 44, 1,000 feet on isophane 43, and 1,800 feet on isophane 41, which in fact—if wee xcept better soil conditions—includes the best winter-wheat growing areas of the State.

As applied to a State like Kansas which comes within the optimum of the winter-wheat region we find that, according to the table (fig. 13), the theoretical optimum range is from between 1,000 and 2,200 feet on isophane 40 to between 1,800 to 3,000 feet on isophane 38, but that, on account of the average late departure of harvest and corresponding early departure for seeding, amounting on the general average to −500 feet, the corrected optimum range would be from below the 1,700-foot level on isophane 40 to between the 1,300 and 2,500 foot levels on isophane 38.

Computing table for seeding and harvest dates and periods of development of spring wheat.

A study of the averages of the reported seeding and harvest dates of spring wheat, similar to that of the winter wheat, resulted in the construction of a computation table to serve as a guide to further investigation of this interesting and important subject.

This table, figure 16, like that of figure 13, is based on the theoretical constants and is, therefore, subject to modification to meet the requirements of regional and local influences which prevail during the period of development. We find that the seeding dates are at intervals of four days to the isophane, while the harvest dates, falling as they do in the season of transition between the accelerating influences of the advance of spring and early summer northward and the advance of late summer and autumn southward, require that the rate for harvest be reduced to two days per isophane. The rate of variation in the period of development from seeding to harvest is also found to be two days to the isophane, minus northward and plus southward.

It is interesting to note that this course of the variation in the periods is just the reverse of that of the winter-wheat periods. The shorter spring-wheat period northward and at high altitudes is in accord with a recognized law of daylight and atmospheric influences by which the period of development during the first half of the season of plant development is shorter with higher latitudes and altitudes in more or less direct proportion to the shorter seasons. The winter-wheat period is longer northward because of the early seeding in the late summer and early autumn and late harvest in midsummer. Thus the influences which contribute to a shorter period of spring development for winter wheat after growth starts, are balanced by the longer autumn period from early seeding.

Because of the optimum conditions for spring wheat which prevail in Minnesota the base for this table has been located on the central isophane (47) of the State with the reported average date of general seeding April 25, general harvest August 14 and period 111 days. Computing from this base, and allowing for corrections

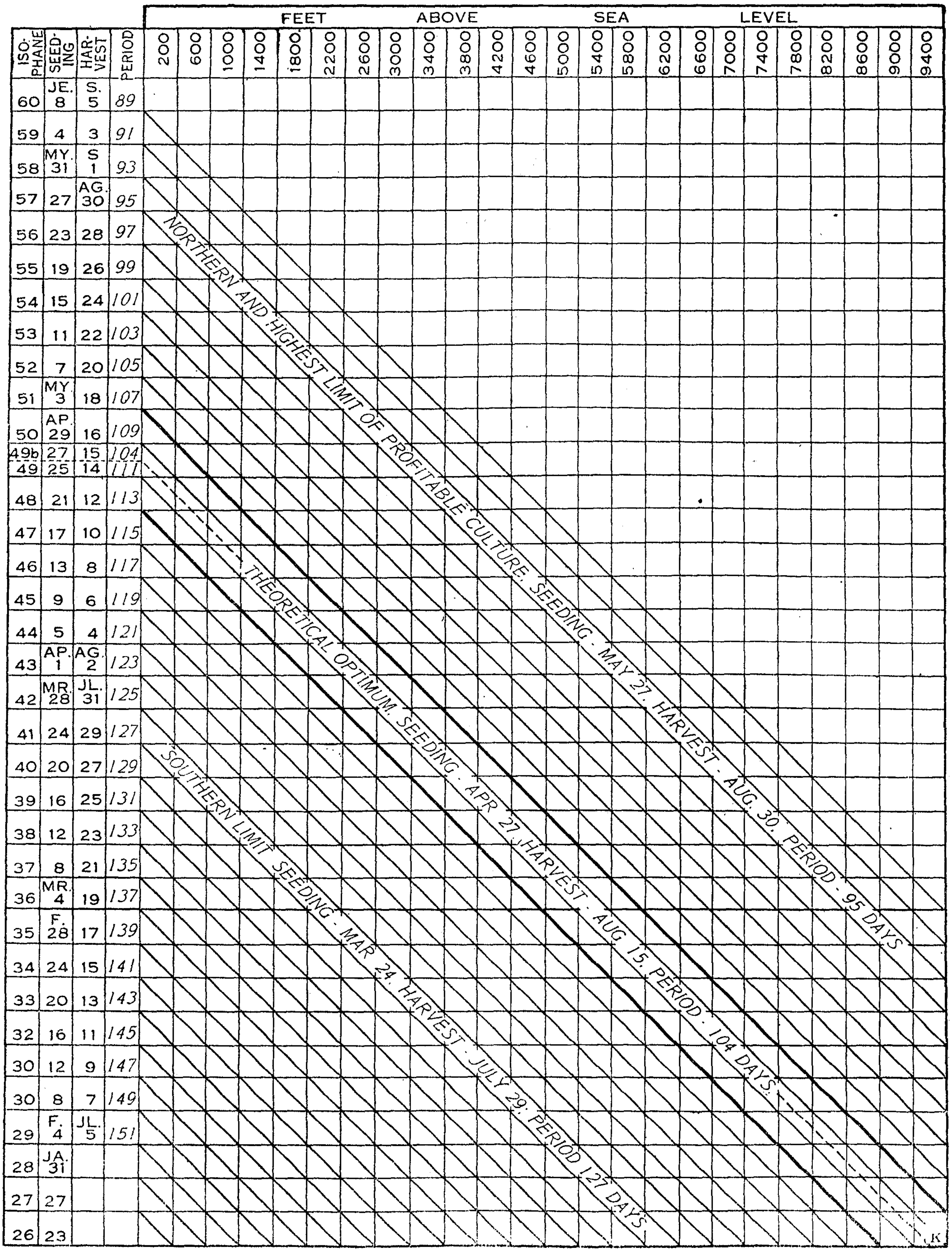


FIG. 16.—Table for computing seeding and harvest dates, periods of development, limits and optimum, for spring wheat in the United States.

to meet the requirements of regional departures, we find that the greater part of North and South Dakota come within the optimum range. These conclusions are significant from the fact that the three States mentioned have relatively the largest average acreage of spring wheat (see fig. 17).

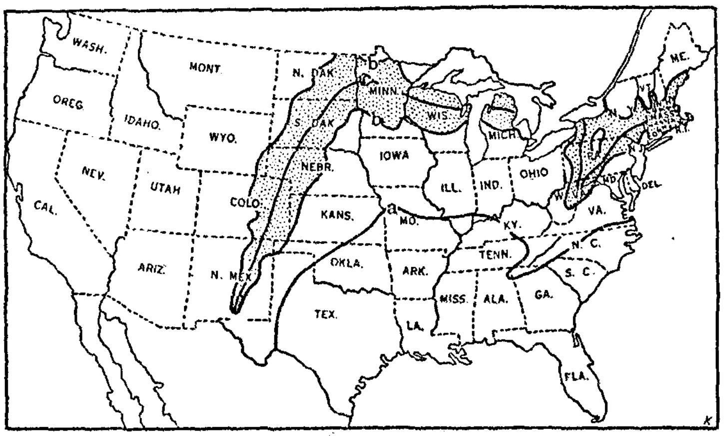


FIG. 17.—Map of the United States to show the approximate range of the culture of spring wheat in the States east of the Rocky Mountains.
a, southern limit; b, optimum range; c, optimum mean.

As applied to West Virginia, we find that, theoretically according to the table, spring wheat could be grown anywhere in the State with the theoretical optimum ranging from about 2,000 in the north to about 3,200 feet in the south; but it is evident that the local climatic conditions of the lower altitudes are such that it may not pay to grow it except within and near the optimum zone.

In Idaho the theoretical optimum, as based on the constant from below 2,600 feet in the north to between 3,800 and 5,000 feet in the south, would be subject to the same corrections as for altitude limits.

In the New England States in isophane 48 the theoretical optimum would be below 1,400 feet, while in isophane 50 it would be below 600 feet and in 52 at sealevel.

A comparison of the period tables for winter and spring wheat indicates that the range of climatic conditions favorable for the spring wheat optimum (figs. 15 and 17) begins about three degrees of latitude (as expressed in isophanes) north of where the optimum range for winter wheat ends, thus indicating that there may be many places where unsuccessful efforts have been made to grow winter wheat in areas whose bioclimatic conditions are more favorable for the growth of spring wheat. Therefore it is believed that this computing-table and isochronal-map method of utilizing the theoretical constant as a basis for investigating the limits and optimums of wheat culture will lead to the determination of facts of special value in the interest of increased food supply. The theoretical constant computed according to the bioclimatic law will indicate the location and range of the favorable optimum areas and regions as well as those unfavorable for the profitable culture of winter or spring wheat, provided other things are equal. Then the investigations can be concentrated in those areas indicated as favorable for spring wheat, in order to determine why they are not utilized. They may be due to unfavorable soil, local climate, more profitable lines of farm practice, or because it has never been tried. It is also indicated that, by using the map calendars of seeding dates, computing tables, and corrections for regional influences, as a guide to the best dates for seeding *it is possible to increase the production of winter and spring wheat without increasing the area and that, by increasing the area within the range of known optimum conditions for each, a marked increase in the general production may be effected at an increased profit to the growers.*

The preceding discussion of the tables for computing the seeding and harvest dates and periods of development for winter and spring wheat in the United States give, it is hoped, a good idea of the method of application of the law and the map-calendar system as a guide and working basis for research and practice, and especially as related to present war-time need for increased food supply. It is applicable not only to wheat but in a like manner to other crops, as the writer has found by applying it to a study of seedtime and harvest dates and periods for corn, oats, barley, rye, buckwheat, flax, cotton, and tobacco.

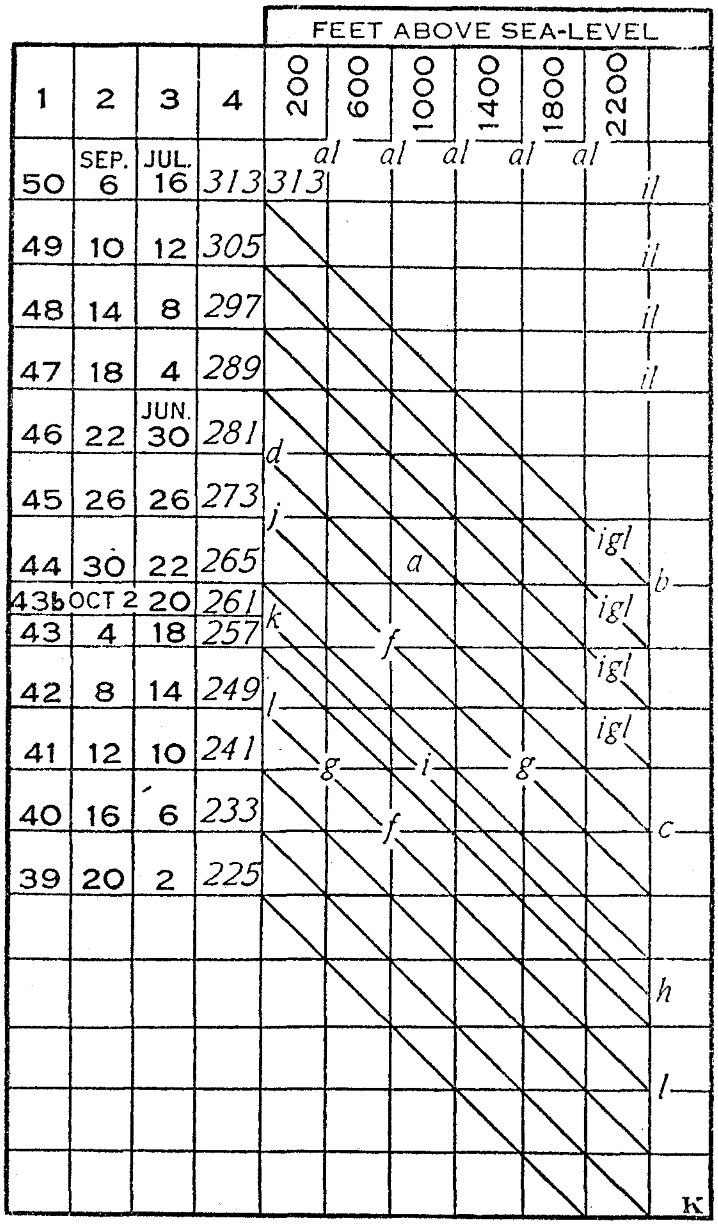
Perhaps the most important subject for further discussion in this connection is the construction of the computing tables and calendars as guides to further research.

Construction of computing tables.—The computing tables illustrated by figures 13 and 16 differ from the map calendars (figs. 9 and 10) and the adjustable calendars of figures 19–23, in that the dates, periods, etc., are given only in the vertical spaces next to the first or isophanal number space on the left. They also differ in having oblique lines designated as isochronal guide lines (lines of equal time) (figs. 13 and 16) by means of which the time in days, as represented by dates, periods, etc., is automatically computed for the given standard altitudes of any and all of the isophanes of a map to which the tables are to be applied.

The following section (fig. 18) from the table in fig. 13 will illustrate the various elements and the terminology of a computing table blank, including those relating to the base dates or optimum range and optimum mean.

The method of procedure in constructing a computing table from a selected base date is first to prepare a blank like that on which figures 13 and 16 are constructed, then enter the standard altitudes in the spaces between the altitude lines (*al.*) beginning with 200 in the first space and continue at intervals of 400 feet to the required limit for the area and subject involved. The isophanal numbers are then entered in the vertical space (*I*) with reference to the isophanal limit of the map to which the table is to apply. For example, in figure 13 we have a range of isophanes from 26 to 50 and in figure 16 from 26 to 60.

The position of the base in the table is determined by its isophanal and altitudinal position on the map, as in the case of the (Sept. 22–June 30, period 281 days) Wooster base as reduced from isophane 44b to 44. The intersection of the isophanal base line (*b*) with altitudinal line (*f*) for the average altitude of 1,000 feet gives the position of the base date (*a*) in the 1,000-foot space on isophanal line 44 and the isochronal guide line (*c*) which intersects the isophanal line (44) at the 1,000-foot line points to the position of the base date (*d*) for 200 feet.



1—isophane numbers; 2—autumn dates; 3—spring dates; 4—development periods for the standard altitude of 200 feet; *al.*—altitude lines; *il.*—isophanal lines; 200—standard average altitude between sealevel and 400 feet; 600 to 2,200—standard average altitudes at intervals of 400 feet. In column 1 there are 12 (39 to 50) 1-degree isophanal numbers and 1 (43b) is a ½-degree isophanal number; *a*—location of the base date; *b*—isophanal base line; *c*—isochronal base line; *d*—date and period constants of the base; *e*—number of the isophanal base line; *ff*—isophanal range of the optimum base; *gg*—altitudinal range of the optimum base; *h*—mean isochronal line of the isophanal range of the optimum; *i*—mean of the altitudinal range of the optimum; *j*—date constants (Sept. 26 and June 26; period 281 days) of the northern and highest limit of the optimum and corresponding isochronal guide line; *k*—date constants (2.20.261) of the mean of the optimum and corresponding isochronal guide line; *l*—date constants (8.14.249) of the southern limit of the optimum and corresponding isochronal guide line.

FIG. 18.—Diagram of elements and terminology used in constructing a computing table.

After the base date is entered in its proper place (*d*) for the 200-foot space, the other dates to correspond to it for the represented isophanes, are entered above and below it as in figure 13, etc.

If the altitude of the base is higher or lower than the given standard, as for the Wooster base on a ½-degree isophane—and the table is being constructed for 1-degree isophanes—both the date for altitude and isophane must be reduced to correspond to those for the standard altitude and the 1-degree isophane. Thus in figure 13 where the Wooster base on isophane 44b (seeding date Sept. 20) is adopted, the date for isophane 44 is 2 days later (Sept. 22) than at 44b, and for the harvest July 2 it is 2 days earlier (June 30); and since the constant rate for the period is 8 days per isophane the period (265 for 44b) is 4 days shorter, giving 261 days for the period.

In a like manner if the altitude of this base had been 1,200 feet for isophane 44b instead of 1,000 feet and the date July 4 instead of July 2, the date would be reduced to that for the 1,000-foot standard by subtracting 2 days (for 200 feet) for harvest, giving July 2 for isophane 44b and June 30 for isophane 44 at 1,000 feet. The corresponding seeding date for 1,200 feet would be September 18, therefore for 1,000 feet it would be plus 2 days, giving September 20, and reduced to isophane 44, the date would be September 22.

The oblique lines (*igl*) are designated as isochronal guide lines because they represent equal time in dates or periods. It will be noted by referring to the map calendar (fig. 10) that the same date (e. g. Aug. 29) is continuous along an obliquely descending course from that date for the 200-foot column. With each successive isophane southward the date is 4 days later and with each successive addition of 400 feet to the given altitude, the date is 4 days earlier. Consequently the date for an isophane southward and at 400 feet higher level remains the same. In other words, going south from a given isophane, the date for an autumn event for each succeeding isophane is later in direct proportion to the progressive earlier date with succeeding increase of 400 feet in altitude so that the same date is continuous whenever this proportion is maintained. Thus if the date is August 29 on isophane 51 at the 200-foot level (fig. 10) it will be the same date on isophane 30 at the 9,000-foot level, or on isophane 43 at the 3,800-foot level and so on.

If all dates are omitted from the calendar except those for the 200-foot space as in figures 13 and 16, and isochronal guide lines are drawn from each date for the 200-foot level through the angles of the squares formed by the altitudinal and isophanal lines, the date for any given isophane and altitude will then be found in the date column at the end of the guide line that is intersected by the isophanal line and the altitudinal line, as for example isophanal line 39, altitude 2,200 feet, the dates are October 20, June 2, the period 225 days in the date column.

This form of computing table is available for computing dates and periods for any cultivated plant from any given base, also for indicating altitudinal and longitudinal limits, range optimums, etc., as determined by the dates of periodical events, so that any desired number of such tables, representing as many different subjects, may be constructed for use with a single isophanal map or list of isophanes and altitudes.

Construction of the adjustable and map calendar of computed dates.—The methods of procedure in constructing a map-calendar are first to prepare a blank with the horizontal lines at the same distance apart as those of the isophanal lines of the map to which it is to be applied and the vertical or altitudinal lines of the blank at the same distance apart as the horizontal ones.

The blank must be long enough to include all of the isophanes and wide enough to include (at intervals of 400 feet) the range of altitude of the region represented by the map or maps to which the calendar is to be attached.

Map-calendars for an isophanal map in ¼×1 degree isophanes (figs. 2 and 10) are constructed by first entering the altitudes (as in the altitude blanks, figs. 19–21), then the isophanal numbers for the State are entered (as in figs. 13 and 16). The base is then selected, e. g., Wooster, Ohio, with the beginning of wheat harvest on July 2. As applied to West Virginia (fig. 19) the base isophane does not pass through the State, therefore the base date is reduced to the corresponding date for isophane 43 at the same altitude (1,000 feet), as follows: Wooster isophane 44b, 1,000 feet minus West Virginia isophane 43, 1,000 feet equals 1½ isophane multiplied by 4 days to the isophane equals 6 days earlier and July 2 minus 6 days equals June 26 as the corresponding base date for West Virginia. This date is then entered on isophanal lines 43 in the 1,000 space. Then on the same isophane in the altitude spaces to the left of the base date the corresponding dates plus 4 days are entered for each interval of 400 feet as June 22 for 600 feet and June 18 for 200 feet and then the dates to the right of the base are entered as June 30, July 4, 8, 12, 16, 20, 24, and 28. When this is done the other dates for each altitude space will be plus one day for each isophanal line above the base line dates and minus one day below it. When thus completed all of the dates as in figure 19 will be the computed constants for all isophanes and all the given altitudes. Then by attaching the completed calendar to the map the constant for any locality in the State will be given. If the average altitude of a place is higher or lower than the given altitude the corresponding date is plus or minus one day for a difference of 100 feet between the average altitude of the locality and the altitude nearest to it as given in the calendar. For example, if the local average altitude is 1,200 the dates for a spring event would be that for 1,000 feet plus 2 days or for 1,400 feet minus 2 days and the reverse for an autumn event.

ISO-PHANE	FEET ABOVE SEA-LEVEL											
	200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	
	JUNE				JULY						AUGUST	
44a	23	27	1	5	9	13	17	21	25	29	2	
44	22	26	30	4	8	12	16	20	24	28	1	
43c	21	25	29	3	7	11	15	19	23	27	31	
43b	20	24	28	2	6	10	14	18	22	26	30	
43a	19	23	27	1	5	9	13	17	21	25	29	
43	18	22	26	30	4	8	12	16	20	24	28	
42c	17	21	25	29	3	7	11	15	19	23	27	
42b	16	20	24	28	2	6	10	14	18	22	26	
42a	15	19	23	27	1	5	9	13	17	21	25	
42	14	18	22	26	30	4	8	12	16	20	24	
41c	13	17	21	25	29	3	7	11	15	19	23	
41b	12	16	20	24	28	2	6	10	14	18	22	
41a	11	15	19	23	27	1	5	9	13	17	21	
41	10	14	18	22	26	30	4	8	12	16	20	
40c	9	13	17	21	25	29	3	7	13	15	19	
				OPTIMUM						5	LIMIT	
									OPTIMUM SPRING WHEAT			G
								4			6	

FIG. 19.—Adjustable harvest calendar for winter wheat for West Virginia, with indication of altitude limits, optimum; and also the optimum lines for spring wheat (illustrating the method).

The separate or adjustable calendars are constructed on the same principle as the map calendar, but differ in their availability for as many crops or periodical practices or events of as many species of plants or animals as may be desired and all used in connection with a single isophanal map. These are prepared without regard to the width of the spaces between the map isophanes, because they are for comparison by the isophanal numbers and not by continuous lines as in the map-calendars.

In constructing an adjustable calendar map for a 1×5 degree isophanal map of the United States, or North America, where the base, as for Wooster, Ohio, comes on a ¼-degree isophane, the date must be reduced to the next 1-degree isophane below it as described on page 29–30. Then proceed as before except that all dates will be at intervals of 4 days for the isophanes as well as for the altitudes. The computed date constants for a 1×5 degree calendar are for the altitudes of a 1-degree isophanal line to the first ¼-degree isophane above it. Therefore, if a locality is between two 1-degree isophanal lines as in the case of Wooster, Ohio, 44b between 44 and 45, it is referred to as in isophane 44, or in isophanal zone 44; thus 44 to 45 would be isophane 44, June 30, July 1, 2, to July 4 for isophane 45. Further corrections can then be made for difference in altitude if it is desired to be thus exact.

It is best, however, in the case of 1-degree isophanal maps of the country or continent to adopt the 4-day coordinate for each 1-degree isophane or isophanal zone, leaving the working out of more exact details in connection with the ¼-degree isophanal map.

For the United States and North America the corrections of the constant date are to be made for departures due to regional influences and for the State maps those due to sectional or local influences, remembering that the computed theoretical constant date should never be taken as final unless it agrees with the actual. In other words, the computed date *must always be considered as the theoretical constant or average by which to measure in days the time departures due to regional and local influences and the intensity of such influences.* Thus, the date constant serves its first purpose as a guide to the investigation of departures and regional or local influences from the results of which corrected map calendars may be prepared for its final purpose of furnishing guides to farm and garden practice.

The winter-wheat harvest calendar.

The winter-wheat harvest calendar for West Virginia (table of fig. 19) is given as an example of an adjustable State calendar for a spring and early summer event for a ¼-degree isophanal map, and to serve as a fairly good guide in forecasting harvest dates for the State under average seasonal conditions.

According to a few available records the beginning of wheat harvest in the season 1917 was between 7 and 13 days later than the average. This conclusion was based on reports from various parts of the country and on phenological records from various stations from Washington, D. C., to Ashland, Oreg., which indicated that the season at the time of beginning of wheat harvest in the winter-wheat region, was on the average 10 days later than the average season, so that with this correction for West Virginia the corrected constant dates for 1917 were found to come very close to the actual average for the season.

Theoretical winter-wheat optimum for West Virginia.—In figure 19 we find that the theoretical optimum for winter wheat, according to the constant as given in figure 18, ranges from the 600-foot level and below in the northern extreme of the State to between the 600 and 1,800 foot levels in the extreme southern areas, and that the theoretical limit is at about 2,600 feet in the northern to above the highest level in the southern parts of the State. The range of the theoretical optimum for spring wheat is indicated by lines 4 and 6 on this calendar to show its relation to the theoretical highest limit of winter wheat (line 5) as based on figures 18 and 16. It will be noted that line 5 comes within the range of the optimum for spring wheat.

These comparisons are given simply as examples of the application of this principle of investigation to the determination of the theoretical limits and optimum for wheat and other crops, species, etc.

The adjustable winter wheat seeding calendar for West Virginia is the same as the map calendar of figure 9.

Adjustable computing calendar of seeding dates for spring wheat in West Virginia.—The adjustable calendar of seeding dates for spring wheat in West Virginia (fig. 20) and the one of harvest dates (fig. 21), are given here as examples of the application of the principle to a spring crop and to show how such a calendar may serve as a guide to investigations and experiments to determine the adaptability of an area or region to crops and farm practices different from those at present adopted.[26]

ISO-PHANE	FEET ABOVE SEA-LEVEL 200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600
44a	6	10	14	18	22	26	30	4	8	12	16	20
44	5	9	13	17	21	25	29	3	7	11	15	19
43c	4	8	12	16	20	24	28	2	6	10	14	18
43b	3	7	11	15	19	23	27	1	5	9	13	17
43a	2	6	10	14	18	22	26	30	4	8	12	16
43	1	5	9	13	17	21	25	29	3	7	11	15
42c	31	4	8	12	16	20	24	28	2	6	10	14
42b	30	3	7	11	15	19	23	27	1	5	9	13
42a	29	2	6	10	14	18	22	26	30	4	8	12
42	28	1	5	9	13	17	21	25	29	3	7	11
41c	27	31	4	8	12	16	20	24	28	2	6	10
41b	26	30	3	7	11	15	19	23	27	1	5	9
41a	25	29	2	6	10	14	18	22	26	30	4	8
41	24	28	1	5	9	13	17	21	25	29	3	7
40c	23	27	31	4	8	12	16	20	24	28	2	6
	MARCH			APRIL							MAY	
							OPTIMUM					6

FIG. 20.—Adjustable seeding calendar for spring wheat for West Virginia, with lines to indicate the dates and altitudes of optimum conditions (to illustrate the method).

The theoretical optimum.—By referring to the computing table of seeding and harvest dates and periods for spring wheat in North America (fig 16), it will be seen that the range of the theoretical optimum, which holds for North and South Dakota and Minnesota, passes into West Virginia at levels between about 2,000 and 3,200 feet on isophane 43c in the northeastern part of the State to 2,600 feet and the highest level at about 42a in Pocahontas, Greenbrier, and Webster Counties in the south-central part, with the theoretical southern and lowest limit for possible spring wheat culture south of the south-

[26] Figures 19 to 21 are given here simply as examples of the method of constructing a calendar for spring and early summer events and to serve as a suggestion that experiments should be tried within and above the indicated optimum.

ern border. This indicates that, with the proper selection of varieties, it may be possible to grow spring wheat in the State, and that there is a considerable area at and above the 2,000-foot level where optimum conditions may prevail. This is based on the assumption that at the higher levels the bioclimatic conditions are the same as or similar to those prevailing in the great spring wheat region of the Dakotas and Minnesota. Whether or not this is true can be determined only by investigations and experiments. The evidence that the climatic conditions are similar to those of some of the spring wheat areas is based on the writer's personal knowledge of the agricultural areas in the mountainous regions of the State. This evidence is found in the altitudinal distribution of the red spruce (*Picea mariana*), the American larch and other trees and plants of the State which are characteristic of the Canadian life zone and common to the regions and altitudes within and above the established optimum in the States where spring wheat is grown successfully.

ISO-PHANE	FEET ABOVE SEA-LEVEL 200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600
44a						AUGUST						
44	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*	*24*	*26*
43c												
43b	*3*	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*	*23*	*25*
43a												
43	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*	*24*
42c												
42b	*1*	*3*	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*	*23*
42a												
42	*31*	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*	*22*
41c												
41b	*30*	*1*	*3*	*5*	*7*	*9*	*11*	*13*	*15*	*17*	*19*	*21*
41a												
41	*29*	*31*	*2*	*4*	*6*	*8*	*10*	*12*	*14*	*16*	*18*	*20*
40c												
SOUTHERN LIMIT									OPTIMUM			G
—JULY—			—AUGUST—									

FIG. 21.—Adjustable harvest calendar for spring wheat for West Virginia.

The average lower limit of the Canadian zone in West Virginia, as indicated by the plant and animal life, ranges from about 2,400 or lower in the glades and high valleys in the northeastern part of the State in Preston County, to about 3,200 feet in isophane 42 in Nicholas and Pocahontas Counties. This is sufficient evidence to warrant a thorough investigation and experimentation as to the adaptability of the tillable land of the higher levels of the State to the culture of spring wheat, at least for local consumption.

The writer knows that there is an extensive aggregate area in the State above 1,800 feet that is admirably adapted to cultivation, in which other crops, like buckwheat, oats, and potatoes find the same optimum that they do in or near the areas in the north where the growth of spring wheat is profitable.

It will be noted that, according to the calendar, the seeding dates for spring wheat within the suggested range of optimum conditions, as well as in other sections of the State, come near the dates on which spring oats is commonly seeded.

While the writer believes that spring wheat can be grown in many sections of West Virginia above an altitude of 1,800 feet, he would not recommend any extensive trial until experiments are conducted on a small scale in different localities with varieties which are most likely to succeed, and it is found that they give better results than are at present attained from winter wheat. This suggestion applies not only to West Virginia but to all areas within the indicated optimum where spring wheat has not been given a fair trial.

For the areas of the State below 1,800 feet it is evident that winter wheat will undoubtedly be the most profitable. However, in case it is desired to experiment with spring wheat the calendar dates will serve as a guide to the time to sow and to when the harvest may be expected.

It will be noticed that the harvesting dates (fig. 21) for practically the entire State come in August; hence a two- instead of a four-day interval to the 1-degree isophane and 400-foot altitude unit is adopted for this event. This two-day interval requires a different construction of the calendar from that of figure 19 in that intervals are one day to ½-degree isophanes and two days to 400 feet.

Adjustable winter- and spring-wheat harvest calendars for the United States.

The adjustable winter- and spring-wheat harvest calendars (figs. 22 and 23) are given in this connection to serve as a guide to forecasting harvest dates. The given dates are necessarily those of the computed constant with Wooster, Ohio (isophane 44, altitude 1,000 feet, and date June 30), as the base for winter wheat and isophane 47, 1,000 feet, in Minnesota as the base for spring wheat. Therefore, in their application to forecasting departures for regions and local areas as well as that for a particular season, the departures for all must be considered and the necessary corrections of the constants made.

With the examples given in the preceding discussion and demonstrations of methods of application to problems

FEET ABOVE SEA LEVEL

ISO-PHANE	200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600	5000	5400	5800	6200	6600	7000	7400	7800	8200	8600	9000	9400	9800	10200	10600	11000	
	SEP.																												
60	5																												
59	3	5																											
58	1	3	5																										
	AUG.																												
57	30	1	3	5																									
56	28	30	1	3	5																								
55	26	28	30	1	3	5																							
54	24	26	28	30	1	3	5																						
53	22	24	26	28	30	1	3	5																					
52	20	22	24	26	28	30	1	3	5																				
51	18	20	22	24	26	28	30	1	3	5																			
50	16	18	20	22	24	26	28	30	1	3	5																		
49	14	16	18	20	22	24	26	28	30	1	3	5																	
48	12	14	16	18	20	22	24	26	28	30	1	3	5																
47	10	12	14	16	18	20	22	24	26	28	30	1	3	5															
46	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5														
45	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5													
44	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5												
43	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5											
	JUL.																												
42	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5										
41	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5									
40	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5								
39	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5							
38	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5						
37	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5					
36	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5				
35	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5			
34	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5		
33	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5	
32	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3	5
31	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1	3
30	7	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	1
29	5	7	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30
28	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26	28
27	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24	26
	JUN																												
26	29	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	2	4	6	8	10	12	14	16	18	20	22	24

JULY — SOUTHERN LIMIT — OPTIMUM — AUGUST — K

HIGHEST LIMIT SEPT.

FIG. 22.—Adjustable harvest calendar for spring wheat for the United States.

in wheat culture, the importance of the bioclimatic law should be sufficiently clear to warrant its adoption in connection with the investigation of any periodical phenomena involving a study of variation in time with different geographical position and local and regional conditions.

SUGGESTIONS FOR INVESTIGATIONS.

Perhaps the greatest fundamental need for investigations which have a direct bearing on further study, development and application of the law and principles outlined in this paper, is in the field of phenology. A vast amount of phenological data beginning as early as 1817, has been collected in this country, but, through a failure to recognize the importance of certain essential details, such as exact localities, altitude and local conditions, designation of species, varieties, individuals, etc., much of it is of practically no value for direct comparisons in connection with up-to-date bioclimatic investigations or to meet the requirements of present needs.

Properly recorded and correctly interpreted, there is nothing perhaps to equal the records of the dates of periodical events in plants and animals as indices to the bioclimatic character of a place or local area, because such events are in direct response, not to one or a few, but to all the complex elements and factors of the environment which no artificial instrument or set of instruments yet available will record. In other words, while species and varieties and even individuals of the same species and variety respond in a more or less different degree to the same complex influences, there are certain constant elements in the response of individuals and groups of varieties and species which, if properly interpreted, will serve as a key to the bioclimatic character and conditions which distinguish a particular region, locality, or place from that of other near-by or distant ones.

Therefore, in order to determine the character of an influence and to measure its extent or intensity as related to a more or less marked departure from a constant in the time of occurrence of important or conspicuous periodical events in one locality or region as compared with that of another, we must have accurately kept records of the dates of such events, not only of native wild species but of introduced and cultivated or domesticated species and varieties.

Relation of periodical events in plants to important events in farm crops and practice.

The results of phenological investigations have led to the conclusion that for every kind of periodical farm and garden practice in which, on account of climatic and seasonal conditions, there is a best time to do the work to secure the best results, there is usually some periodical event in the seasonal development of one or more species of wild or cultivated plants on the farm or in the immediate locality which will serve as a guide to this best time for any given locality or season. If such guide plants do not occur on the farm they can be found among the ornamental trees and shrubs and hardy flowering plants of other localities or countries and transplanted. There are doubtless many of these ornamentals that will serve the purpose of guides to the best time to plant and when the harvest may be expected and at the same time serve to supply the common need of ornamental planting around the farmhouse, outbuildings, and along the fences of the cultivated fields.

The periodical event of the falling of the flower catkins of the Carolina poplar has been found to be one of the best guides to the general early or late character of one season as compared with the average, while the opening of the leaf buds and unfolding of the leaves serve as reliable guides to the progress of spring.

The various magnolias in their succession of flowering events serve as excellent guides to the rate of progress of spring and the time to do various kinds of work. The ornamental Spiraeas, Deutzias, Diervillas, climbing roses, and Clematis among the ornamentals and the dogwood, service tree, redbud, and oaks among the native trees of the middle and eastern region of the United States are more or less constant in their responses to prevailing local influences which are indicative of the time to plant certain field and garden crops. The opening of the leaf and flower buds and the flowering of the common fruit trees and shrubs of almost every farm serve as more or less reliable guides to the time to spray for certain insect and plant diseases. There is, in fact, a long list of plants from which selections can be made to provide a succession of daily events from the earliest seedtime in the spring until the ending of the seeding and harvest of autumn.

One of the greatest values of these seedtime and harvest guides is in the index they furnish to the character of the immediate local influences of climate, weather, topography, etc., which contribute to a generally earlier or later departure from the date constants of a crop calendar. Thus, with the calendar to serve as a guide to the approximate time for a certain event in practice, the local index plant will give the exact time for any place, farm, or field.

Very little specific study has been made in this country of the subject of index plants to determine their relation to different periodical events in farm and garden practice, especially with reference to the relative value of different species and varieties as to the constancy of their periodical responses to seasonal influences year after year. Therefore, it is apparent that among the subjects requiring thorough systematic investigation that of the relation of phenology to agriculture is among the most important.

System of phenological records.

Among the requisites for phenological investigations is a uniform system to be followed by all investigators and observers so far as their records relate to the essential events of a selected list of species and varieties. This is important in order that the records from all localities may be correlated, tabulated, and studied with reference to the investigation of broad general problems like the bio-

	FEET ABOVE SEA LEVEL																											
ISO-PHANE	200	600	1000	1400	1800	2200	2600	3000	3400	3800	4200	4600	5000	5400	5800	6200	6600	7000	7400	7800	8200	8600	9000	9400	9800	10200	10600	11000
57	AUG. 13																											
56	9	13																										
55	5	9	13																									
54	1	5	9	13																								
53	JUL. 28	1	5	9	13																							
52	24	28	1	5	9	13																						
51	20	24	28	1	5	9	13																					
50	16	20	24	28	1	5	9	13																				
49	12	16	20	24	28	1	5	9	13																			
48	8	12	16	20	24	28	1	5	9	13																		
47	4	8	12	16	20	24	28	1	5	9	13																	
46	JUN. 30	4	8	12	16	20	24	28	1	5	9	13																
45	26	30	4	8	12	16	20	24	28	1	5	9	13															
44	22	26	30	4	8	12	16	20	24	28	1	5	9	13														
43	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13													
42	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13												
41	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13											
40	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13										
39	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13									
38	MAY 29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13								
37	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13							
36	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13						
35	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13					
34	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13				
33	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13			
32	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13		
31	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13	
30	APR. 27	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9	13
29	23	27	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5	9
28	19	23	27	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1	5
27	15	19	23	27	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28	1
26	11	15	19	23	27	1	5	9	13	17	21	25	29	2	6	10	14	18	22	26	30	4	8	12	16	20	24	28

← APRIL → | ← MAY → | ← JUNE → | ← JULY → | ← AUGUST →

FIG. 23.—Adjustable harvest calendar for winter wheat for the United States.

climatic law and the regional and local departures from its constants. Otherwise, each investigator should work out and follow the system which, for particular species and line of research, seems to be best for the attainment of special results.

The writer would recommend the standard form of permanent 5 by 8 inches record card (Form A):

U. S. Department of Agriculture.

BUREAU OF ENTOMOLOGY, FOREST INSECTS.

A. Phenological records. Year ....

Locality..................	County..................	State..................
Latitude or isophane.......	Longitude or pheno-meridian....	Altitude................
Station No.................	Observer..................	Slope..................
Species: *Pyrus malus*.......	Common name: *Apple*..........	....

Species, variety, or number.	a.	b.	c.	d.	e.	f.	g.	h.	i.
Ben Davis									
Grimes Golden............									
Baldwin									
York Imperial............									

This form provides for the entering of the essential data including the description of the local area in which a phenological station is located.

The spaces with letters *a* to *i* are for the name or designation of the seasonal events as given in the following lists for different types of plants, and the blank spaces below the designated events are for the date of occurrence. This blank may be used for consecutive records on the same species, variety, or individual, year after year or for a number of them the same year as desired.

Standard phenological events for plants.

(The small letters correspond to those of the lettered spaces of the blank.)

1. Trees and shrubs, in general:

Deciduous.

a. First buds opening.
b. First leaves unfolding.
c. First flowers open, including catkins, etc.
d. First flowers falling, including catkins, etc.
e. First winter buds forming.
f. First seed or fruit ripe.
g. First leaves coloring.
h. First leaves falling.

Conifers.

a. First buds opening or new growth showing.
b. First full-grown needles.
c. First winter buds forming.
d. First pollen falling.
e. *Last pollen falling.*

2. Herbaceous perennials, wild or uncultivated:
a. First appearance above ground, or first growth.
b. First flowers open.
c. *First flowers fading or falling.*
d. All flowers faded or fallen.
e. First seed or fruit ripe.
f. First injury by frost.
g. All foliage killed by frost.

3. Annuals, uncultivated, general:
a. First appearance above ground.
b. First appearance of stem.
c. First flowers open.
d. First flowers fading or falling.
e. All flowers faded or fallen.
f. First seed ripe.

4. Annuals, cultivated, ornamentals:
a. First appearance above ground.
b. First appearance of stem.
c. First flowers open.

4. Annuals, cultivated, ornamental:—con.
d. *First flowers fading or fallen.*
e. All flowers faded or fallen.
f. First seed ripe.
g. First injury by frost.
h. All killed by frost.

5. *Perennials, cultivated, ornamentals:*
a. First appearance above ground, or first growth.
b. First flowers open.
c. First flowers fading or fallen.
d. All flowers faded or fallen.
e. First seed or fruit ripe.
f. *First injury by frost.*
g. All foliage killed by frost.

6. Field crops, cereals and forage:
a. First planted.
b. First above ground.
c. First appearance of stem.
d. First appearance of spike or head.
e. *First bloom.*
f. First bloom fading or falling.
g. All bloom faded or fallen.
h. First ripe or ready for harvest, or first harvest.
i. *Last harvested.*

7. Cotton:
a. *First planted.*
b. First appearance above ground.
c. First fruiting branch.
d. First flower.
e. First mature boll open.
f. First picking.

8. Winter grains:

Autumn—
a. First planted.
b. Last planted.
c. First appearance above ground.

Spring—
d. *First jointing.*
e. First appearance of heads.
f. First bloom.
g. First ripe.
h. First harvest.
i. Last harvest.

9. Spring grains:
a. First planted.
b. Last planted.
c. First jointed.
d. First heads.
e. First bloom.
f. *First ripe.*
g. First harvest.
h. Last harvest.

10. Potatoes:
a. First planting.
b. Last planting.
c. First appearance above ground.
d. First flowers.
e. First tubers ready for use.
f. Vines dying normally.
g. First harvest.
h. Last harvest.

Standard phenological events for insects.

For first and succeeding seasonal generations, from first activity in spring:

a. First appearance in spring or summer, or first attack, first activity, etc.
b. First eggs.
c. First larvæ.
d. First pupæ.
e. First new adults transformed.
f. First emergence or flight.
g. All emerged or transformed to adults.
h. Beginning of hibernation or overwintering.

Standard form A was proposed by the writer, although it is different in several respects from the form of blanks which he has used during the past 20 years as follows:

U. S. Department of Agriculture.

BUREAU OF ENTOMOLOGY, FOREST INSECTS.

B. Locality data. Phenological Station No.............

NEAREST POST OFFICE (distance—direction)..................................
LOCAL DESIGNATION—name or location by meridian, etc., or both....................
LATITUDE—within ½ degree..................................
LONGITUDE—within ½ degree..................................
ALTITUDE—above mean tide, within 200 feet..................................
EXPOSURE: South—North—East—West—SE.—SW.—NE.—NW....................
ANGLE OF EXPOSURE: Approximate degree, ...°, or slope gentle—steep—precipitous
....
SOIL: Shale—sandy—clay—loam—light—dark—wet—dry—swamp—bog................
TOPOGRAPHY: Narrow or broad valley—hilly—mountain—narrow or broad plateau—distance from plateau border..................................
ENVIRONMENT: Presence (distance from) or absence of stream (size)—lake (size)—ocean or arm—dense or open forest—brush—shrub—sod—barren..............................
....
REMARKS..................................
....
....

NOTE.—This blank is intended especially for permanent observation stations, but may be used to advantage wherever practical. Cross (X) data corresponding to those of observation station or locality. Give description where such is called for.

C. Plants.

Phenological record.

Observer .... Station No. .....

Locality. Nearest post office. Latitude. Longitude.	Date.	Altitude.	Names of plants or individual nos.	Buds.			Leaves.			Flowers.							Catkins.			Fruit.			
				Normal.	Swelling.	Opening.	Unfolding.	First full grown.	Falling.	Buds, swelling.	Opening.	First out.	Half out.	Full.	Fading.	Fallen.	Out.	Flowers, opening.	Pollen, falling.	Forming.	¼, ½, or 1.	Ripening.	Falling.

D. Insects.

Phenological record.

Observer .... Station No. ......

Locality. Nearest post-office. Latitude. Longitude.	Date.	Altitude.	Names of insects and host no.	Parent adult.			Eggs.			Larvæ.			Pupæ.			Adults.			Emerging.			Attack.		
				First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.	First.	Maximum.	Last.

These forms (B to D) meet the requirements of economy of time in making the entries and all printed on the standard card 10.5 x 18.4 cm. The events for a given date are indicated by "checks" or X. They are adapted to general records on a number of species and events on the same blank or to continuous records on the events of a single species, and also available for summaries and comparisons of the records on the same species at many different localities, but they do not meet the requirements for a general standard. A full discussion of the subject of phenological observations and records would require more space than would be allowed here and therefore will be deferred for a special paper.

General biological investigations.

The bio-climatic law, supplemented by the system of computing calendars and tables, is adapted to many lines of biological research, in fact practically all subjects relating to organisms which involve a comparison of the dates of periodical events under the different geographical conditions and regional and local environments affecting such events.

In general, the problem of geographical distribution and life zones can be studied by this method with prospects of most satisfactory results especially as applied to altitudinal limits of northern and southern distribution, the optimum, etc. This not only applies to the wild or indigenous species but also to introduced and cultivated or domesticated species and varieties and the weed and insect pests of the farm, garden, and forest.

Entomological investigations.

In entomology, in addition to the lines of investigation suggested under general biology, there are many subjects to which the isophanal map and computing table principle of research and practice is adapted. In fact, as stated in the introduction, this paper is founded on investigations originally intended for application to entomological research and practice with special reference to forest entomology. It was early recognized by the writer that there was need of knowledge on rates of variation in the seasonal history events of an insect pest with variations in latitude and altitude as a basis for determining the proper dates and periods to begin and end control operations in different localities within the range of its depredations.

As compared with plants, which are stationary with always constant succession in their periodical events, insects present much more complex and difficult problems. This is on account of their movements from place to place where the influences of local environment are different, the inconstant succession of the periodical events in the seasonal history of some species and the overlapping of two or more seasonal generations of others, but it is just such complications and difficulties which demand the attention of the up-to-date scientific investigator and should serve to stimulate the desire and determination to solve them.

In the practice of applying remedies by means of spraying with poison or contact insecticides or by cutting, barking, or burning the infested trees, considerable progress has already been made in the methods of designating the time to do the work to meet the requirements of local conditions.

The old style of spraying calendar, which gave the same spraying date for an entire State regardless of the variation in latitude and altitude, is now obsolete and, instead, some periodical event in the plant to which the spray is to be applied is given as the index to the time to do the work; thus, in conformity to phenological law, the modern calendar applies to any latitude or altitude.

There is, however, much need of detailed investigation of the seasonal histories of the insects, in relation to the periodical events in their hosts, and in other plants of the same environment, to determine the index plant which is most constant in its periodical events as coincident with the critical events in the seasonal activities of the insect.

We have a good example of this host relationship in the white pine bark louse (*Pineus strobi*) which has alternate hosts in the white pine and red spruce.

The seasonal history of the insect is so nicely adjusted to periodical events of each of its alternate hosts [27] that the vital period, as to the time to spray to kill it, is coincident with the beginning of growth on the twigs of the white pine and the opening of the buds on the red spruce.

Thus, while a map-calendar for this species will serve to give the approximate or average date for any locality, the phenological event gives the exact date for the place and season.

Pathological investigations.

It is evident that many of the fungous and bacterial organisms, which produce diseases of plants, conform to the same bioclimatic law as that affecting their hosts and are, therefore, subject to the application of the phenological principle of investigation.

The writer, however, is not sufficiently familiar with this subject to warrant further discussion except to suggest that pathologists give the matter their serious consideration.

[27] On the white pine the insect lives on the bark of the trunk, branches and twigs where it is protected through all of the year, except a very short period in the spring, by a covering of wax wool. The critical period is when it hatches and is migrating to other positions on the bark or to the new growth on the twigs, which occurs at the time new growth starts. Part of the brood attains wings and migrates to the spruce where they deposit eggs on the needles from which young hatch and locate on the bark of the twig. In the spring these develop rapidly and lay a mass of eggs which hatch just as the buds are opening and the young crawl in the buds and locate at the base of the embryonic needles, thus producing cone-like galls. All of the individuals which develop in the galls migrate back to the pine and lay eggs on the needles from which overwintering broods develop.

Investigation of agricultural economy.

With those investigators and demonstrators who are employed to render a public service through the Federal and State institutions established in the interest of agriculture, the ultimate object of all investigation, systematic as well as economic, is application of the acquired new information to the economy of farm, garden and forestry practice in the growth, protection and utilization of the products, thereby increasing the supply for the essential needs of the consumers in all industries and professions and meeting the fundamental requirement of the maintenance of armies and successful prosecutions of war against our enemies. Therefore, anything in the results of scientific investigation that has a promise of contributing to a more rapid advancement of improved methods, greater economy, and increased production is worthy of serious consideration and a thorough trial in connection with both scientific research and practical application.

SUMMARY.

There is in general a safest and best time for periodical farm and garden practices to guard against insects and diseases and otherwise to secure the best returns from the expenditures of money and labor.

By utilizing the dates of periodical events in the seasonal development of common plants at one place in connection with calendars and maps based on a bioclimatic law the corresponding safest and best dates can be approximately determined for any place in the country (p. 5).

According to the bioclimatic law there is a country-wide average rate of variation in the time of occurrence of regular periodical events in plants and animals between different geographical positions as defined by latitude, longitude, and altitude. This rate is 4 days for each, one degree of latitude, 5 degrees of longitude and 400 feet of altitude (p. 7).

The results of the more recent investigations, including a comprehensive study and comparison of well known facts of geographical distribution of plants and animals and those determined by phenological observations together with the conclusions as to the rates of variation in dates of periodical events with variation in geographical position, as recorded in literature and observed by the writer, have furnished sufficient evidence to establish the bioclimatic law as a reliable guide and working basis (p. 9).

Isophanal lines drawn on a map in a northwestern course from the eastern border at the rate of 1 degree of latitude to 5 degrees of longitude serve as a diagramatic expression of the law as related to latitude and longitude of the land surface. Therefore, one of these lines across a map of the continent or minor political division represents, for any given level, the same bioclimatic conditions and the same date for a given phenological event.

The isophane, together with any given level, serves as a bioclimatic constant by means of which the date of a phenological event, plus or minus departures for regional and local influences, can be computed for any place along its course to correspond with that of a determined base. The phenological date constant thus computed serves also as a measure in time and distance of the rate of departure and the intensity of the influences which cause it (pp. 13 and 18).

The departures of the actual from the computed constants serve as the most reliable basis for interpreting regional and local influences toward retarding or accelerating the date of events; also as a guide to the required plus or minus corrections of the computed to approximate more closely the actual dates (p. 14).

The county averages of over 40,000 reports, covering the entire wheat-growing area of the country and giving dates of general seeding and beginning of harvest of winter wheat, compared with the computed dates for the same counties, showed that in general there was but a slight difference between the reported and computed harvest dates (except in regions where there is a marked retarding or accelerating influence), thus presenting substantial evidence in support of the law as a reliable guide to the predetermination of dates of periodical events and bioclimatic conditions for any county or quadrangle unit (p. 14).

In general, for the whole country, the departures for spring and early summer events are plus the constant for valleys and coasts and minus for plains, plateaus, and mountains, and the reverse for late summer and autumn events. This relation of departures to depressions and elevations of land surface also holds for regions and minor areas down to those of a few acres or even a few rods in extent, so that it may be considered as a law of topographic influence on phenological phenomena (p. 18).

The constant character of the departures from the computed constant, all pointing in the same direction within a region, is most significant evidence of the existence and wide range of accelerating and retarding influences which must be associated with peculiar climatic variations from the average of the whole country. Thus, through a study of a single periodical event, a guide has been found to the comparative intensity of the influences in the various regions of the country which contribute to an earlier or later departure from the theoretical constant for the actual average dates of the event of beginning of wheat harvest (p. 19.)

Knowing the number of days' departure of a given season from the average, the departures of the date of an event from the theoretical constant for a region and the date of the event for the season at a given base, the corresponding later or earlier date for any other place will be the computed date for the place, plus or minus the number of days in the seasonal and regional departures (p. 20).

It is well known that wheat can be sown too early and too late to yield the best results. Between these extremes there is an optimum or best date. It has been shown by experiments that the average safe time to seed winter wheat to avoid serious damage from the fall attack of the Hessian fly is also the best average time to otherwise secure the best yield of grain (p. 20).

The period of seasonal development of a spring crop, as spring wheat, is shorter with higher latitudes and altitudes in more or less direct proportion to the shorter season, while the period for winter crops, like winter wheat, is longer northward, because of the early seeding in the late summer and early autumn and late harvest in midsummer (p. 27).

There is a northern, southern, and altitudinal limit to the profitable culture of winter wheat and other crops, between which there is an optimum zone for the most profitable culture. By means of computing tables these limits and optimums can be approximately determined and shown on maps to serve as a guide to research and practice in determining the facts as related to regional and local conditions.

The computing table and isochronal map method of utilizing the theoretical constant as a basis for investigating the limits and optimums of wheat culture should lead to the determination of facts of special value in the interest of increased food supply, since it appears that, by utilizing the map calendars of seeding dates, computing tables and corrections for regional influences as a guide to the best dates for seeding, it should be possible to increase the production of winter and spring wheat without increasing the area and that, by increasing the area within the range of known optimum conditions for each, a marked increase in the general production should be effected at an increased profit to the growers (pp. 25 and 29).

The examples of map calendars and computing tables demonstrate the practical application of the law as a guide and working basis in research and practice, and especially as related to present war-time need for increased wheat supply. They are not only applicable to wheat but in a like manner to other crops, as the writer has found by applying them to a study of seedtime and harvest dates and periods for corn, oats, barley, rye, buckwheat, flax, cotton, and tobacco (p. 29).

The computing tables automatically compute the time in days, as represented by dates and periods, for average altitudes on or near the isophanes of a map to which the tables are to be applied (p. 30).

The computed dates and periods, altitude limits, optimums, etc., must be considered as the theoretical constants or averages by which to measure in days the time departures due to regional and local influences, and the intensity of such influences. Thus the date constant serves its first purpose as a guide to the investigation of departures and regional or local influences, from the results of which corrected map calendars may be prepared for their final purpose of furnishing guides to farm and garden practice (p. 32).

The seeding and harvest dates for spring wheat in West Virginia are given in the adjustable calendars as examples of the application of the principle to a spring crop and to show how such a calendar may serve as a guide to investigations and experiments to determine the adaptability of an area or region to crops and farm practices different from those at present adopted (p. 33).

With the examples given and the demonstrations of methods of application to problems in wheat culture, the importance of the bioclimatic law should be sufficiently clear to warrant its adoption in connection with the investigation of any periodical phenomena involving a study of variation in time with different geographical position and local and regional conditions (p. 32).

Properly recorded and correctly interpreted, there is nothing perhaps to equal the records of the dates of periodical events in plants and animals as indices to the bioclimatic character of a place or local area, because such events are in direct response, not to one or a few but to all the complex elements and factors of the environment, including climate, which no artificial instrument or set of instruments yet available will record (p. 35).

Every farmer and gardener should note the flowering or other conspicuous events in the wild and cultivated plants on his farm at the time of the earliest, latest, and calendar dates of planting, and then note the result in the comparative development, maturing, and yield of the crop from planting on the dates which were coincident with those of certain noted events (p. 23).

One of the greatest values of these natural seedtime and harvest guides is in the index they furnish to the character of the immediate local influences of climate, weather, topography, etc., which contribute to a generally earlier or later departure from the date constants of a crop calendar. Thus, with the calendar to serve as a guide to the approximate time for a certain event in practice, an established index plant will give the exact time for any place, farm, or field.

Among the requisites for phenological investigations is a uniform system to be followed by all investigators and observers so far as their records relate to the essential events of a selected list of species and varieties. This is important in order that the records from all localities may be correlated, tabulated, and studied with reference to the investigation of broad general problems like the bioclimatic law and the regional and local departures from its constants (p. 35, 37).

The old style of spraying and planting calendar, which gave the same date of operation for an entire State, regardless of the variation in latitude and altitude, is now obsolete and, instead, some periodical event in the plant to which the spray is to be applied is given as the index to the time to do the work. Thus, in conformity to the bioclimatic law, the modern calendar applies to any given latitude or altitude (p. 39).

The discussion in this paper relating to the application of the bioclimatic law to research and practice is not intended as even an attempt to solve any problems in agriculture, but merely to describe and give examples of a system and methods by which many of the problems can be solved.

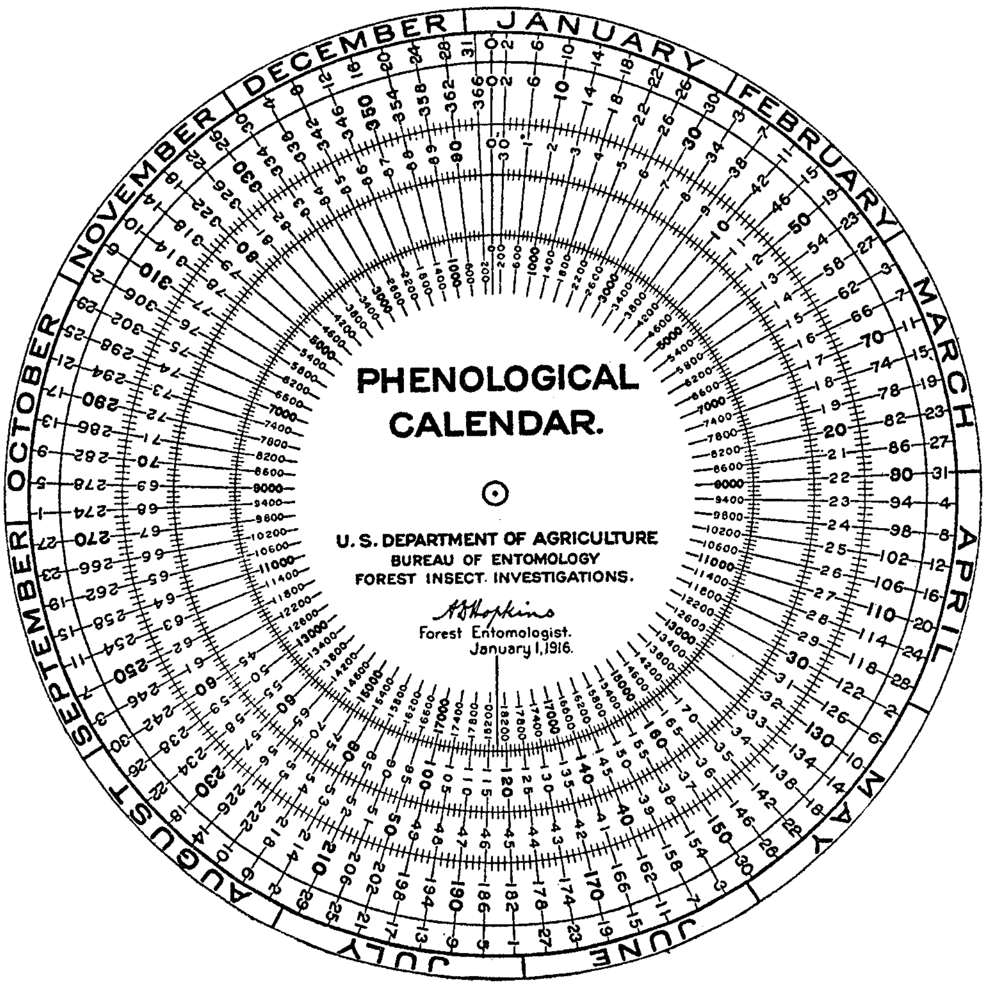


FIG. 24.—Phenological disk calendar for the computation of dates and altitude limits from latitude, longitude and altitude, and from isophanes and altitude.